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Characterization of Stormwater Runoff from a Bridge Deck and Approach Highway, Effects on Receiving Water Quality in Austin, Texas

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Abstract

Nonpoint source pollution represents one of the largest environmental problems currently facing water quality professionals. A fraction of this pollution is conveyed to receiving waters by stormwater drainage from highways. Some highway runoff is treated by structural or non-structural systems (best management practices [BMPs]) or is diverted to municipal treatment systems depending on locale. However, much highway runoff and almost all bridge deck runoff enter receiving streams without treatment. Highway runoff may contain suspended solids, metals, oil and grease, fecal coliform, and oxygen demanding organics. Highway runoff characteristics have been reported in some detail over the years; however limited data on the characteristics of runoff from bridge decks are available. The objectives of this study are:

1) characterization of bridge deck and approach highway stormwater runoff in Austin, Texas
2) a statistical comparison of the water quality characteristics of stormwater runoff from the two sources, and
3) an assessment of the impacts of the runoff on the quality of the receiving water.

Flow-weighted composite and grab samples of runoff were collected from a bridge and approach highway. The average daily traffic count was 58,000 vehicles per day. The sampling period extended over a period of more than one year. ISCO® automatic flow monitoring and sampling equipment was installed to record runoff flow and collect samples at the two sites. The samples were analyzed for a suite of runoff constituents including: total and volatile suspended solids, (TSS/VSS), total and dissolved metals, phosphorus, nitrogen species, chemical oxygen demand (COD), and coliform organisms. A total of 15 storm events at the bridge site and 16 storm events at the adjacent approach highway were sampled. The receiving water is Barton Creek, an ephemeral stream with peak flows exceeding 30,000 ft^3/s. Water quality and flow data for Barton Creek at Loop

360 were obtained from the United States Geological Survey (USGS) and compared with the composite runoff samples from the bridge deck.

The initial runoff data from the two sites were compared with runoff data observed at other highway sites in Austin, TX as well as national sites to determine the relative quality of the samples collected in this study. The observed data for the two sites were representative of local conditions, but generally the concentrations of constituents were lower than the concentrations reported for samples collected nationally. The bridge and approach highway runoff data were subjected to paired-event hypothesis testing to establish any significant differences in concentrations observed for the bridge site and approach highway sites. The results of the paired events testing indicate that the concentrations observed at the bridge site were significantly lower or statistically equal to the concentrations observed at the approach highway site. Therefore highway runoff data may be used as a conservative surrogate for bridge runoff for total copper, dissolved copper, total lead, COD, total phosphorus, total Kjeldahl nitrogen (TKN), TSS, and VSS in the absence of bridge runoff data. Highway runoff data for total zinc, dissolved zinc, nitrate-nitrogen (NO_3-N), dissolved phosphorus, fecal coliform, and oil and grease may be used as a more accurate proxy for bridge deck runoff. There was no instance in which the concentration observed at the bridge site was significantly higher than that at the approach highway.

At the average storm flow, concentrations for total metals (copper, lead, and zinc) and volatile suspended solids from the Loop 360 bridge were higher than the average concentrations in Barton Creek at the bridge site. The average concentrations of all other constituents for which Barton Creek data are available were lower in the bridge runoff than in the Creek. The loading from bridge deck runoff was calculated to estimate pollutant contributions from the Loop 360 bridge to Barton Creek. The results indicate that the impact of storm water runoff from the bridge deck was small. Loading of typical storm water constituents was much greater in the creek upstream of the bridge than the load contributed by the bridge deck runoff. The difference was several orders of magnitude in most cases. For example, the total suspended solids load upstream of the bridge is 7 x 10^6 kg/yr (1.54 x 10^7 lb/yr) compared to the load of 257 kg/yr (567 lb/yr) contributed by the runoff from the bridge. The greatest increase in annual loading from the bridge deck among all the storm water constituents analyzed was 0.056% for total zinc. Therefore, the storm water runoff from the Loop 360 bridge has very little impact on the water quality of Barton Creek.

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CHAPTER 1 INTRODUCTION

1.1 Overview

Nonpoint source pollution that is discharged into receiving streams is one of the major water quality concerns in the environment today. A large fraction of this pollution is transported in urban stormwater runoff to receiving waters. Population growth and the resulting land development increase urbanization of many watersheds. Urban development increases the amount of impervious cover in a given watershed; that in turn result in many changes in the environment. These watershed changes include, but are not limited to: decreases in times of concentration of runoff, higher peak flows, altered sedimentation/erosion processes, changes in water quality, reduction in biodiversity, and damage to infrastructure. Two subsets of urban stormwater runoff are runoff from highway bridge decks and runoff from highway pavements. Extensive efforts have been undertaken to characterize the quality of highway pavement runoff over the last 20 years. Conversely, very little emphasis has been placed on quantifying the concentrations of constituents of bridge deck runoff. The objectives of this study are an evaluation of the characteristics of runoff from a highway bridge deck and adjacent approach highway in Austin, TX, and a statistical comparison of the water quality of paired runoff samples. Constituent loadings were calculated using measured flow rates and observed concentration data for specific constituents in the bridge runoff, and historical flow rates and concentration data reported for Barton Creek by the U.S. Geological Survey (USGS). These loadings were compared to assess the environmental impact of the bridge runoff on the water quality of the creek.

1.2 Regulatory Framework

Two main permitting issues were addressed by this research, one federal and one state. On a federal level, Clean Water Act Section 404 (CWA) states that "any discharge of dredged or fill material into the navigable waters incidental to any activity having as its purpose bringing an area of the navigable waters into a use to which it was not previously subject, where the flow or circulation of navigable waters may be impaired or the reach of such waters be reduced" is required to have a permit (40 CFR 404). The U.S. Army Corps of Engineers has jurisdiction over the issuance of the "404 permits" that call for the avoidance of negative impacts on wetlands and surface waters where possible and practical, minimization of the remaining impacts, and compensation for any unavoidable impacts. A 404 permit may be issued individually or coverage may be obtained under the Nationwide Permit (NWP). A NWP may be issued for certain classes of activities. The Army Corps of Engineers takes into account the need to maintain the beneficial uses of a particular water body or wetland while allowing for development and progress.

The State of Texas regulates water quality through the Texas Commission on Environmental Quality (TCEQ). TCEQ grants a 401 certification, if the planned development will not impair water quality. A 401 certification is needed prior to the issuance of the 404 permit. A 401 certification is issued, if best management practices (BMPs) are instituted to satisfactorily minimize any impacts on receiving water quality. These controls may be for erosion/sedimentation processes or for the minimization of total suspended solids (TSS) post-construction. Since the TCEQ 401 certification applies to highway bridge projects, the characterization of runoff from highway bridge decks is needed to assess any potential impacts on the receiving waters. Additionally, post construction BMPs for TSS control are required for bridge decks unless a NWP 14 permit is approved. The need to establish the concentrations of constituents in bridge deck stormwater runoff is reinforced further by the fact that many problems could arise from the installation of post-construction BMPs on new or existing bridges.

This research project also addresses the Total Maximum Daily Load (TMDL) program, which is another regulatory program that is administered by the United States Environmental Protection Agency (EPA). The TMDL program requires each of the 50 states to submit a list to EPA of all water bodies within the state that do not meet the designated use and the constituent that causes the impairment. This list is known as the 303(d) list, and is generated every four years. Ideally, TMDLs are developed as a means for all stakeholders in the watershed to share equitably in the costs of restoring the water quality of a water body to a level specified by the designated uses. Each stakeholder within the watershed is issued a waste load allocation for the pollutant that causes the impairment. The premise is that controlling the concentration of the designated constituent to a predetermined concentration will result in returning the receiving water to compliance with water quality standards typically within a period of 15 to 20 years depending on the level of impairment. All TMDLs are subject to a period of public comment during which time the stakeholders may weigh in on the stipulations set forth in the TMDL. The TMDL program is designed to be a cooperative effort in which industrial dischargers, agricultural dischargers, regulators, developers, state agencies, municipal governments, environmental groups, academics, and other citizens participate in the planning, data collection, determination of numeric targets, and implementation of the plans.

Few TMDLs have specifically addressed highway pollution as a significant contributor to water quality impairments in the State of Texas. However, as more and more TMDLs are developed, the Texas Department of Transportation (TxDOT) will be included increasingly in these plans. TxDOT is a potential stakeholder in every major watershed in the state. Therefore, TxDOT may be required to participate in all phases of the TMDL program from data collection through implementation of structural BMPs to meet the prescribed waste load allocations. This participation could be costly, but a true assessment of the water quality impacts associated with bridge and highway operations will ensure that TxDOT will not be unduly burdened by the restoration process. An accurate, scientific understanding of the concentrations of pollutants being discharged from bridges and approach highways in Central Texas may result in millions of dollars in savings in construction and delay costs associated with TMDL compliance.

This report characterizes the water quality of stormwater runoff that is discharged from highway bridge and approach sections on Loop 360 in Austin, Texas. The characterization results will be compared with similar data collected locally and regionally to establish the relative quality of the runoff collected at the Loop 360 sites to the previously monitored runoff quality. Statistical analyses were employed to compare the concentrations of the same constituent in the runoff samples from the bridge and highway approach section.

1.3 Scope of Work

The primary objective of this project is the characterization of stormwater runoff from bridge deck, approach highway, and water quality in receiving streams in Central Texas. A bridge and associated highway approach section on Loop 360 in South Austin was selected for this study. An average daily traffic count (ADT) of 58,000 cars was reported for this site (CAMPO, 2002). The bridge deck and approach highway were representative of those in Central Texas. Flow weighted composite samples were taken to establish event mean concentrations (EMCs). Grab samples also were collected intermittently to analyze for oil and grease and coliform bacteria. The samples were analyzed by an EPA certified lab, Environmental Laboratory Services, a division of the Lower Colorado River Authority (LCRA) located in Austin, Texas. The quality of base flow and storm flow in the receiving water were determined from data collected by the USGS, and the changes in concentration and load in the receiving water attributable to storm water runoff from the bridge were assessed. The EMCs observed in the study were compared to those reported previously for three locations in the Austin area and with data reported in an extensive nationwide study to determine the relative quality of the runoff. The EMCs generated by these sampling efforts were compiled into a database and subjected to a robust statistical analysis to determine whether significant differences exist between the concentrations of specific stormwater constituents at the bridge and approach highway. The statistical analysis also included the generation of 95% confidence intervals to quantify the expected differences, if any, between the bridge deck and highway runoff. This analysis led to the identification of those stormwater constituents for which highway runoff could be used as a surrogate for bridge deck runoff.

The annual load of selected constituents from the Loop 360 Bridge to Barton Creek was estimated based on the observed concentrations together with measurements of average annual rainfall. The observed concentrations were compared to the Texas Surface Water Quality Standards (TAC Title 30, Part 1, Chapter 307) and aggregate eco-region nutrient criteria proposed by the EPA (TCEQ, 1988).

The annual load contributed by the bridge for the constituents sampled was compared to the annual load in Barton Creek. Annual loads in Barton Creek at the Loop 360 bridge were calculated using average concentrations of each constituent in composite samples collected by the USGS from April 1997 until June 2002 and average flows in Barton Creek from 1978 to 2001. An assessment of impacts of the runoff from the Loop 360 bridge on the water quality of Barton Creek was made based on this comparison. The impact of pollutant spills on the quality of the receiving water was not assessed.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Nonpoint source pollution has moved to the forefront of concerns regarding maintaining environmental water quality. Watersheds and Nonpoint Source Section of EPA reports that nonpoint source pollution is the leading cause of water pollution in the United States. Additionally, nonpoint source pollution is the principal source of water quality impairments reported for estuaries (USEPA, 2005). Dramatic increases in the amount and effectiveness of controls placed on industrial and municipal discharges have been seen over the last 20 years. This effort has not always resulted in a proportional increase in receiving water quality. The major reason for this water quality impairment is nonpoint source pollution. Pitt (1991) reported that the annual volume of urban runoff is slightly greater than the annual volume of sanitary wastewater. This fact clearly underscores the need to institute practices which minimize, control, or mitigate these stormwater flows. Nonpoint source pollution is unpredictable; therefore, characterization and subsequent control of nonpoint source pollution is much more complex than typical municipal wastewater discharges (Hvitved-Jacobson and Yousef, 1991).

A subset of nonpoint source pollution is highway runoff. The public road system in the United States consists of approximately 6.3 million kilometers (3.91 million miles) of which 60% is paved (Eldin, 2002). Furthermore, the paved area of this system exceeds 50,000 km^2 (19,305 mi^2). Infrastructure for collecting highway runoff varies by locale, but highway runoff may be conveyed by either combined or separate sewer systems. This paper excludes research on highway runoff that drains to combined sewer systems since an entirely different management protocol must be implemented for such flows (Eldin, 2002).

2.2 Sources of Highway Contaminants

There are three major sources of contaminants found in highway runoff: moving vehicles, stationary construction activities including roadway maintenance, and atmospheric deposition. The pavement material also may be a source of particulate matter but to a lesser degree than the other sources. A variety of mechanisms of deposition for each of the major sources have been identified (Hvitved-Jacobson and Yousef, 1991). Constituents in highway runoff may be generated by moving vehicles from fuel combustion products, transmission fluid and coolant losses, transported load losses, oil leaks, fuel leaks, losses of hydraulic steering and braking fluids, and degradation of tires and vehicle moving parts. Motor vehicle exhaust is a major contributor to the pollutants found in highway runoff. Hvitved-Jacobson and Yousef (1991) note that 7.5% of vehicle related particulates are attributable directly to settled particles discharged from vehicle exhaust.

Stationary construction and road maintenance activities also may contribute to the pollutant loadings found in highway stormwater. Eldin (2002) reports that heavy metals such as aluminum, arsenic, lead, and mercury, as well as hydrocarbon compounds may be released by the various construction and maintenance materials that commonly are applied to roadway surfaces. A toxicity based approach was applied by Huber et al. (2001) to investigate the environmental effects of construction and maintenance chemicals. Acute and chronic toxicity testing was carried out using a freshwater algae species and *Daphnia magna*. The results indicate that aluminum is the principal toxic metal found in the 100 commonly used construction and maintenance materials that were investigated in this study. The presence of soil served as a mitigating factor in these toxicity experiments. Sorption onto the particle surfaces and biodegradation were proposed mechanisms for the reduced toxicity. A regional effect was noted in the toxicity results. A marked difference in the chemical makeup of pavements depending on locale was attributed to the fact that highway pavement surfaces, typically Portland cement concrete (PCC) or asphalt cement concrete (ACC) contain predominantly local materials. This difference also was observed in ecotoxicological analyses in which PCC and ACC pavements from different states were compared (Eldin, 2002).

Atmospheric deposition of pollutants is a key pathway for contaminants to reach highway surfaces. Wanielista and Yousef (1993) reported that the nitrogen, copper, and cadmium found in urban stormwater runoff originated predominantly in the rainwater. The results of 2-year study of five roadways in Minnesota reported by Davis et al. (1999) indicated that concentrations of dissolved nitrate and dissolved ammonia in rainfall were significant sources for those constituents in the highway runoff. Davis et al. (1999) concluded that up to 50% of the dissolved nitrate and dissolved ammonia in the runoff may be attributed directly to atmospheric sources, i.e. rainwater. An even stronger association between concentrations of nitrogen compounds in rainfall to nutrients in runoff was reported by Irish et al. (1998) who observed that the concentration of nitrate in precipitation accounted for 50 to 100 percent of the concentration in runoff. In addition, up to 22 percent of the total phosphorus load observed in the highway runoff could be attributed directly to phosphorus in rainfall.

The atmospheric processes that result in the formation of acid rain including the cycle of nitrogen-oxide and sulfur-oxide compounds in the highway environment are discussed by Ball et al. (1991). These compounds that are generated by combustion of fossil fuels by motor vehicles are oxidized into strong acids by ozone and hydrogen peroxide in the presence of water vapor, and finally are deposited as sulfuric acid and nitric acid onto the roadway surface. These strong acids have the potential to degrade runoff quality and negatively impact biota in the receiving water. Therefore, site specific data was gathered when developing a local stormwater management plan because the phenomena are related to local meteorology.

2.3 Factors Affecting Highway Runoff

An exhaustive list of factors that determine the quality of highway runoff is offered by Wanielista and Yousef (1993). This list includes climate, surrounding land use, average daily traffic volume, type of traffic, differences in paving materials, street condition and level of repair, antecedent precipitation, street sweeping practices, and quantities of air pollution fallout. In their study of Austin, Texas highway runoff, contradictory results regarding the impact of ADT on runoff quality were reported by Barrett et al. (1995a). Other factors such as dust fall, previous storm runoff volume, and pavement maintenance showed good correlation with solids loadings in the highway runoff.

An analysis of gutter systems were incorporated by Davis et al. (1999) who concluded that the concentrations of TSS, total chromium, and total zinc were higher in highway runoff from guttered sites than at non-guttered sites in Minnesota. Reduced time of concentration caused by the installation of gutter systems was cited as the probable reason for increased concentrations. In contrast, concentrations of total phosphorus and fecal *Streptococcus* bacteria were greater at non-guttered sites than at guttered sites. Davis et al. (1999) also investigated the effect of antecedent dry period (or latent period), and ADT on the quality of runoff from highway roadway surfaces. No statistical correlation between most runoff constituents and antecedent dry period was observed. However, concentrations of total phosphorus, dissolved sulfate, and total zinc were significantly correlated with antecedent dry period. Loadings of these parameters were not correlated. The causal link between average traffic volume and loadings of stormwater constituents reported by Davis et al. (1999) concurs with research results reported by Barrett et al. (1996). There is no significant link between ADT and concentrations or loadings of constituents in highway runoff. These findings at first may seem counterintuitive in light of the fact that the apparent source of many of the pollutants found in highway runoff is traffic. However, the average daily traffic volume is not the best variable that is available to forecast pollutant loads or concentrations for a given stretch of roadway.

A set of regression equations that may be used to isolate the controlling independent variables for a variety of highway stormwater parameters were developed by Irish et al. (1998). This study is unique in that characteristics of highway runoff from natural storms and simulated storms were incorporated into the analysis of the observed data. Complete control over many of the potentially explanatory variables, e.g. rainfall intensity and total rainfall, was possible for the simulated storms. Solids loading can be described by four independent variables, catchment area normalized volumetric flow, rainfall intensity, antecedent dry period length, and intensity of the preceding storm, as well as an arbitrary intercept term. Solids loading will increase with increased flow, rainfall intensity, and antecedent dry period, and will decrease with more intense preceding storms. Similar analyses were performed for chemical oxygen demand (COD), oil and grease, nutrients, and metals. Traffic loads were adequate predictors for COD and metals while rainfall intensity and antecedent dry period were the main drivers for nutrient loadings.

Similar statistical analyses of highway runoff data collected in California over the four-year period from 1997 – 2001 were performed by Kayhanian et al. (2003) who reported no direct correlation between annual average daily traffic volume and concentrations of pollutants in stormwater; thus confirming the findings reported by Barrett et al. (1998). Traffic count helped predict concentrations in runoff when used as a variable in a larger multiple regression model. There is some agreement between the multivariate regression analyses that were performed by both research teams. The explanatory variables that had the most influence on concentrations in runoff from California highways were: antecedent dry period, seasonal cumulative rainfall, total event rainfall, maximum rain intensity, drainage area, and land use. A model containing annual ADT, total event rainfall, seasonal cumulative rainfall, and antecedent dry period was found to significantly predict 70% of the constituents analyzed. The annual average daily traffic count alone may only be used as a general indicator of quality of highway runoff.

2.4 Existing Studies on Bridge Runoff Characterization

During the late 1970s and early 1980s, the Florida Department of Transportation funded several studies on highway runoff from bridges. The fate of heavy metals in storm water runoff from highway bridges on Lake Ivanhoe and Lake Lucien near Orlando, Florida was reported by Yousef et al. (1984). Water samples were collected from bridges both with and without scupper drains. Heavy metal concentrations were higher in sediment samples from sites with scuppers than without them. Therefore, the authors recommended that the use of scupper drains in new construction be reduced as much as possible and that the bridge runoff be directed toward either side for maximum removal of heavy metals by overland flow to encourage percolation before the runoff reaches the receiving water. Runoff samples from scupper drains consisted mainly of particulate matter and only 12 percent of total metals in the samples were in dissolved form. Most of the metals in the lake were in the bottom sediment and little metal was in the water column.

A retention/detention pond that receives runoff from Maitland Boulevard Bridge crossing Interstate 4 near Orlando, Florida also was sampled by Yousef et al. (1984). Similar to the findings at Lake Ivanhoe, the sediment at the bottom of the ponds contained 95% of the total heavy metals. Therefore, the data indicate that sediments in bridge runoff carry most of the metals and that retention/detention ponds are effective in the removal of a large fraction of heavy metals in bridge runoff.

A water quality assessment of storm water runoff from a heavily used urban highway bridge in Miami, Florida was conducted by McKenzie and Irwin (1983) who collected runoff samples from a 1.43 acre bridge section of Interstate 95 during 5 storm events. Concentrations and loadings of typical water quality parameters were reported and compared to two other previously finished studies to evaluate the effect of average daily traffic on the concentrations of constituents in runoff. Concentrations of nitrate, phosphorus, lead and zinc in runoff from the medium-traffic Interstate 4 site (50,000

ADT) were higher than concentrations observed for the low-traffic U.S. Highway 27 site (4,000 ADT) or the high-traffic Interstate 95 site (70,000 ADT). However, levels of cadmium and copper were about the same at all three sites (McKenzie and Irwin, 1983).

There are several factors other than average traffic that influence pollutant loads. Among storm events of the same magnitude of runoff, the most significant factor influencing the constituent loads was concentration. Rainfall intensity and runoff volume also affected constituent loadings. Higher intensity storms transported 60 percent of the suspended solids load in the first 4 minutes, whereas lower intensity storms transported only about 15 percent of the TSS load. Loadings of other constituents responded similarly to rainfall intensity (McKenzie and Irwin, 1983).

Irwin and Losey (1978) conducted a water quality assessment of runoff from the Ochlockonee River Bridge on U.S. Highway 27, a rural highway bridge near Tallahassee, Florida. Average traffic count during the study was 4200 vehicles per day. About 15% of the storm water drained directly from the bridge surface to the river, and the rest of the runoff to a grassy floodplain. Samples were collected from the bridge surface using a simulated storm event, bulk precipitation samples and Ochlockonee River (taken by the USGS). The results of the study indicated that bridge runoff is not a significant annual source of nutrient loadings; however, runoff dominates all other sources during a particular storm event. Therefore, the runoff produces a "shock loading" on an aquatic system.

The impact of the bridge runoff loading on water quality in the receiving water was small. Analyses of the bulk precipitation samples indicated that a significant percentage of the constituent loading from the bridge surface came from atmospheric deposition. This point is well illustrated in the case of suspended solids, for which the annual bulk precipitation load was 138 pounds or 11% of the 1,210 pounds estimated to be in the runoff from the bridge surface. The estimated bridge loads were based on the entire surface area of the bridge (72,800 ft^2); however, only about 10,000 ft^2 of the bridge surface drained directly to the river. The rest of the runoff flowed to a grassy floodplain. The annual loadings contributed by the runoff from the bridge were less than 0.005% of the annual loads in the river for most of the constituents that were monitored (Irwin and Losey, 1978).

Runoff from the Mopac (Loop 1) Expressway Bridge over Walnut Creek in Austin, Texas drains through vertical openings in the road (Walsh et al., 1997). Runoff samples were collected from the bridge surface via a PVC pipe connected to the vertical openings in the bridge surface. The approximate ADT was 47,000 vehicles per day. Concentrations of TSS, COD, nitrates, zinc, and lead in the bridge runoff were similar to the median concentrations in runoff from highway sites with ADT greater than 30,000 vehicles per day reported by Driscoll et al. (1990).

Griffin et al. (2002) monitored the quality of runoff from the I-220 Bridge which spans Cross Lake in Shreveport, Louisiana. The bridge was designed with a “closed” drainage system that diverts runoff from the lake which is a source of drinking water. The runoff is discharged into a concrete lined holding pond. Traffic counts during the study varied from about 30,000 to 42,650 vehicles per day. Approximately 70% of the pollutants, measured as COD, were associated with suspended or settleable solids and could be removed by sedimentation. More than half of the suspended solids were inorganic matter. Therefore, a large portion of the sediment and associated pollutants, e.g. heavy metals, in the bridge runoff could be removed in the holding ponds. The reported average TSS removal was 85% (Griffin et al., 2002). Periodic cleaning of the holding pond and disposal of sediment and associated pollutants would be required in order to keep the process effective.

Runoff from an elevated 1,400-foot long, 1-acre curbed bridge (I-94) over Lower Nemahbin Lake in Wisconsin drained directly into the lake through regularly spaced open scupper drains (Dupuis et al., 1985). The ADT on the eastbound lane alone was 7,500 vehicles per day. The results reported by Dupuis et al. (1985) indicated localized increases in metals and salt concentrations in sediments and aquatic plants near the bridge deck scupper drains. However, no significant adverse effect on aquatic biota near the drains was reported.

Dupuis (2002) summarized the results from six different case studies that specifically addressed impacts on water quality of receiving waters attributed to runoff from bridge decks. Dupuis concluded that the main constituents in bridge runoff that are of concern and the impact on aquatic life (e.g. acute and chronic toxicity to aquatic life) are particulates (e.g. "carriers" of other constituents and sedimentation effects on aquatic life), nutrients (e.g. eutrophication), and salts (e.g. aquatic life toxicity and drinking water supply taste). More recently, polycyclic aromatic hydrocarbons (PAHs) have also been investigated from a toxicity perspective.

2.5 Effects of Highway Runoff on Receiving Waters and Biota

Potential impacts of stormwater runoff on the environment have been recognized by the EPA. In 1987, the federal government amended the Clean Water Act of 1972 to include provisions to address the potential impacts of stormwater discharges. This amendment requires stormwater permitting for medium and large municipalities. In 1999, the CWA was amended to include the Phase II rules which require some small municipalities (>10,000 people) and all construction sites greater than one acre to obtain a permit (40 CFR 122-3).

The site and time specific nature of the effect of highway runoff on a receiving water body are important considerations in assessing its environmental impacts. The effect of highway runoff on Danz Creek in the Austin, Texas area was evaluated by Barrett et al. (1995c) who compared concentrations of TSS, oil and grease, and zinc in 14 paired samples of runoff that were collected upstream and downstream of a newly opened highway right-of-way. The observed concentrations of TSS, oil and grease, and zinc in the creek were higher downstream of the highway; however the concentrations were less than the water quality standards recommended to protect aquatic life.

The most commonly reported contaminants found in highway runoff are lead, cadmium, nickel, zinc, various combustion by-products (PAHs), and oil and grease (Scanlon, 1991). The reported ecological effects of exposure to lead are the potential to bind to calcium sites in animals as well as interfere with the central nervous system, metabolism/growth, and the reproductive system. Lead is bioaccumulative and has been linked to kidney disease as well as impairment of the red blood cells which facilitate oxygen transfer. The removal of lead containing additives from gasoline has drastically reduced the quantity of lead found in highway runoff. The toxic effects of cadmium are similar to those reported for lead with the addition of hypertension as a chronic effect of exposure to high concentrations of cadmium. Nickel and zinc are micronutrients for many species at low concentrations. However, high concentrations of nickel may cause liver problems in animals along with inhibition of reproductive and metabolic rates. Exposure to high concentrations of zinc may result in gastrointestinal disorders, impaired liver enzyme function, reduced bone metabolism, anemia, and interference with copper metabolism (Scanlon, 1991).

Two mechanisms of stormwater creek impairment caused by urban runoff were identified by Pitt (1991) to be the bioaccumulation of lead and zinc associated with polluted sediment and increased stream flows. Bioaccumulation was linked to the die-off or displacement of the native fish species and development of more pollution tolerant non-native species. Peak flows in a creek doubled as a result of the increase in the impervious cover of the drainage area causing alteration of channel morphology and riparian vegetation. These creek changes flushed the majority of contaminated sediments through the creek, but still negatively impacted the local fish population (Pitt, 1991).

Bioassays indicate that highway runoff is strongly inhibitory to algal populations for samples collected from high traffic volume roads with antecedent dry periods of greater than two weeks. Conversely, runoff from roads with lower traffic counts or shorter antecedent dry periods had a stimulatory effect on algal populations (Wanielista and Yousef, 1993). Whole effluent toxicity tests are commonly employed to determine the environmental effects of stormwater pollution because of the potential for antagonistic or synergistic effects of the constituents found in runoff. Factors that influence the overall toxic effects of runoff on a receiving water include, but are not limited to: pH, temperature, hardness, alkalinity, dissolved oxygen, and the presence of complexing agents (Pitt, 1991).

Pitt (1991) performed extensive bioassay testing to determine the exact mechanism by which highway stormwater induces chronic and acute toxicity. The authors performed tests with water and sediment samples from 15 urban sites in the Toronto, Ontario metropolitan area on a variety of indicator species. The experiment was designed to identify genotoxicity, cytotoxicity, along with more general chronic and acute toxicity. Ecotoxicological effects of sediment in highway runoff, as well as effluents of extended detention ponds and of combined sewer overflows (CSO) were quantified by implementation of the Microdot™ sediment test by Marsalek et al. (1999). The highest frequencies for moderate (24.2%) and severe (19.3%) toxicity were observed for sediment in runoff from multi-lane divided highway sites based on 125 tests. CSO effluent was less toxic than highway runoff (Marsalek et al., 1999).

Assessment of the true toxic effect of these discharges on the ecosystem is difficult because of the ephemeral nature of stormwater runoff. Some organisms can tolerate short-term exposures to highly toxic effluents, but long-term exposure to less toxic concentrations may cause inhibition of the organism. Duration of exposure, dose of potential toxicants, and timing vary in response to changes in hydrology, meteorological conditions, and other environmental factors. Lakes and reservoirs respond to cumulative pollutant loads over an extended period of time, while streams respond more acutely to individual events (Webster et al., 2003).

Consideration of the unique characteristics of each bridge, runoff constituents, and type of water body are essential to accurately evaluate the impacts that a bridge runoff will have on the quality of the receiving water. Specific factors include bridge deck length and width, traffic volume, concentrations of constituents of runoff, and type of receiving water (i.e. river, lake, or estuary).

Storm water runoff generally does not result in acute toxicity in bioassay tests conducted on organisms from streams and lakes that receive highway runoff; however runoff may produce a toxic response under site-specific conditions. Chronic toxicity that might result from bioaccumulation of metals, sediments, or other constituents in runoff has not been elaborated in much detail. Concentrations of nutrients (i.e. nitrogen and phosphorus) in highway runoff generally are lower than in runoff from undeveloped land (Barrett et al., 1995a).

Characterization of bridge runoff and/or assessment of the impacts of bridge runoff on a receiving water body have not been reported in great detail in the published literature. In contrast, the characterization and impact assessment of highway runoff are discussed in much more detail. Many of the studies on bridge deck runoff were conducted in the late 1970s and the early 1980s when leaded gasoline powered motor vehicles. In addition, much of the observed data that were reported were for sites in Florida. Therefore, the published bridge deck runoff data for the most part are not recent and are geographically limited in scope.

The limited data that are available focus on metals and show that localized increases in pollutant concentrations occur when bridge runoff drains directly into the receiving stream without any pretreatment such as flow over adjacent shoulders or grassy areas.

However, no long-term increases throughout the water body and no adverse effects on the stream biota on a large scale have been documented. Most of the published information indicates that heavy metals are critical in assessing the impact on plants and other stream biota; however, most of the metals were associated with the sediments in the water body, rather than the dissolved form, which is more acutely toxic to fish and other organisms.

Dupuis (2002) concluded that,

> "Very few, if any, studies detailing water quality impacts of bridges, or spills from bridges to receiving waters, have been conducted. Several studies have described potential or hypothetical impacts, and a number of measures have been identified to reduce these impacts. Those studies that did specifically address bridge runoff concluded that direct drainage of runoff to certain types of water bodies, especially small lakes, can lead to localized increases in certain pollutant concentrations, such as metals in sediments and/or aquatic biota. However, most of these studies did not consider whether such increases adversely affect aquatic biota as well as other water uses."

Dupuis (2002) also summarized the results of a nationwide survey of environmental managers and bridge design experts in 50 state transportation agencies as well as selected university and other researchers. The results of the survey showed that,

> "Issues of storm water runoff, maintenance activities, and spills associated with bridges are becoming increasingly prominent in many states, especially for larger bridges. State and federal authorities now often advocate the use of some form of containment and/or partial treatment system to be used on storm water runoff from bridges, rather than drain it directly to the receiving stream or lake."

CHAPTER 3 MATERIALS AND METHODS

3.1 Site Description

3.1.1 General

The study site is located within the city limits of Austin, Texas. Austin is a fast growing, mid-sized city located in the southwestern United States. The estimated population of the Austin metropolitan area in 2000 was 859,000. There is no rail commuting system in this area; therefore transportation primarily is based on the federal, state, and local roadways. Approximately 28% all transportation funding in the metropolitan area is invested in roadway projects (CAMPO, 2000).

3.1.2 Loop 360 Bridge Deck

Loop 360 is a 14-mile stretch of state highway that extends from US 290 southwest of Austin, northward and eastward to US 183 just west of the Missouri Pacific Railroad right-of-way (TxDOT, 2003). The location of the project site is Loop 360 west of South Lamar Blvd. and east of Loop 1 (Mopac). The site consists of a bridge, an approach highway, and a receiving stream. The bridge spans Barton Creek, an ephemeral stream with peak flows exceeding 30,000 cubic feet per second. The approach highway is immediately adjacent to the bridge to the southeast. A GIS image of the project site is presented in Figure 1.

The average daily traffic volume is 58,000 vehicles per day (CAMPO, 2002). Key criteria for selection of this site are:

1) The runoff from a portion of the bridge deck drains by gravity to a single point.
2) A USGS flow gauging station that records real-time flow data for Barton Creek is located between the two decks of the bridge.
3) There is easy access to the bridge from parking areas, and the sampling personnel are protected from traffic by guardrails.

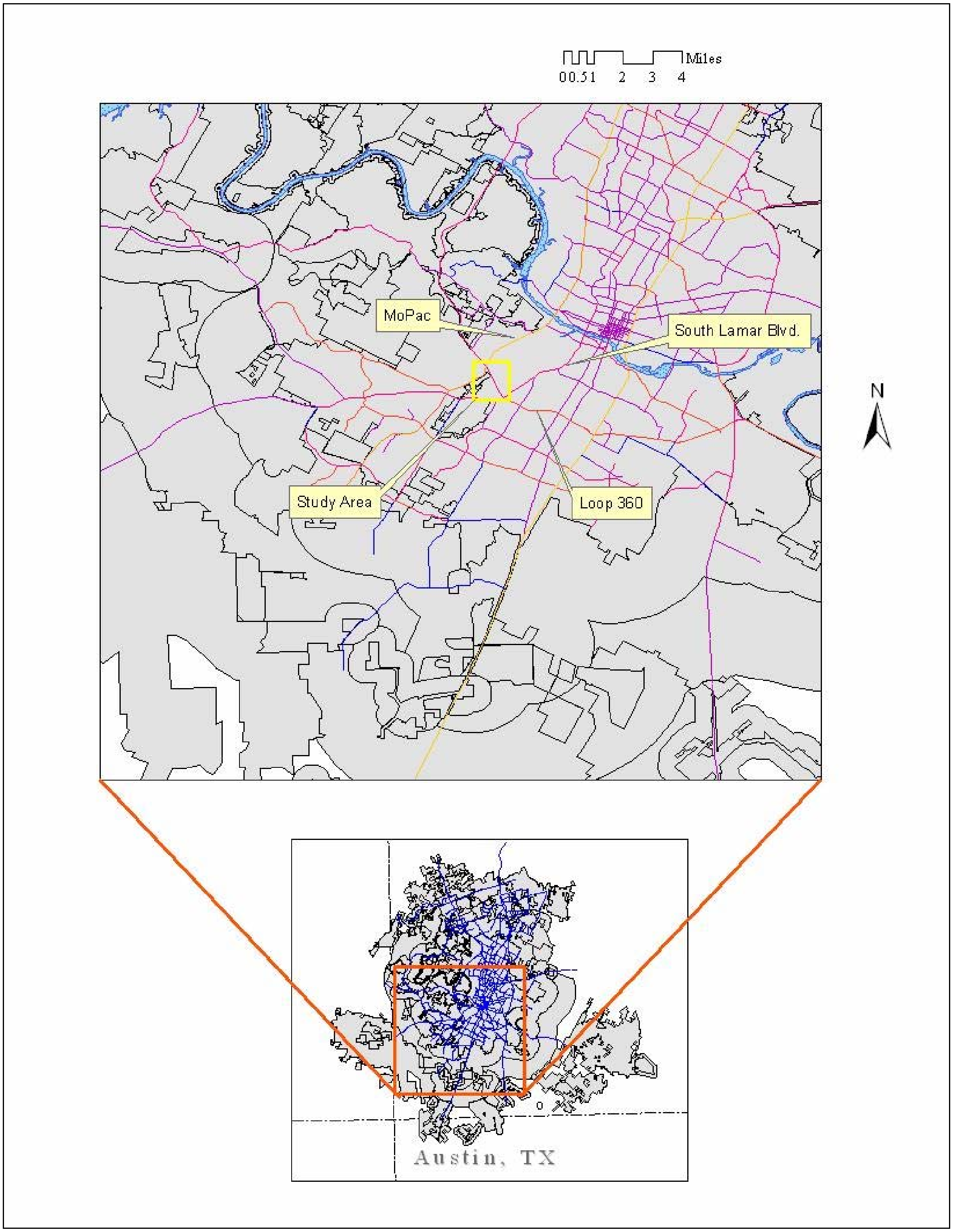

Figure 1 Map of Study Area in Austin, Texas

The USGS provides real-time flow data as well as an historical archive of flow data and water quality data that dates back to February 1978. USGS collects composite water quality samples from Barton Creek for 4 storm events and 2 baseline events annually (USGS, 2004).

The Loop 360 bridge over Barton Creek consists of 2 separate T-beam concrete decks supported by circular reinforced concrete piers. One deck carries 2 lanes of traffic to the northwest, while the other deck provides 2 lanes for travel to the southeast. Each bridge is 375 feet long and 40 feet wide, resulting in a surface area of 30,000 ft^2. The surfaces of the bridge deck are completely impervious, but contain penetrations for drainage (scupper drains) at an interval of 1 drain every 6 linear feet. Not all of the surface area of the bridge contributes to the samples collected at the bridge site since the 2 decks are separate and some of the scupper drains along each guardrail discharge directly into the creek. Field observation of the volume of runoff during normal rain events indicate that the last two sections of the southbound lanes contribute to the runoff samples during normal rainfall events. Therefore, the estimated drainage area was approximately 2,357 ft^2 ($219m^2$) and the assumed runoff coefficient was 0.95. Photos of the Loop 360 bridge are presented in Figure 2 and Figure 3.

Figure 2 Loop 360 Bridge, Austin, TX

Figure 3 Security Box at the Loop 360 Bridge, Austin, TX

3.1.3 Loop 360 Approach Highway

The approach highway is located immediately to the southeast of the Loop 360 bridge. The length of highway that drains to the catchment point extends southeast from the bridge to the crest of the South Lamar overpass. The drainage area for the approach highway is approximately 250,000 ft^2 (23,270 m^2). A photo of the approach highway monitoring point is shown in Figure 4. Several key requirements were satisfied by this site:

1) All runoff from the roadway surface is captured by curb inlets and conveyed through culverts to a single point.
2) There are no other land uses associated with this drainage area (e.g. no commercial, industrial, or residential inputs).
3) The approach roadway is easily accessible and is situated immediately adjacent to the Loop 360 bridge described above.

Figure 4 Flow Monitoring and Runoff Point Approach Highway, Austin, TX

3.1.4 Barton Creek

Barton Creek is an ephemeral stream with peak flows exceeding 30,000 ft^3/s or 850,000 L/s. However, there are extended periods during the year when there is little or no flow in the creek. The USGS has monitored flows in Barton Creek at several locations since 1978. A photograph of Barton Creek flowing underneath the Loop 360 bridge is presented in Figure 5.

Figure 5 Barton Creek at Loop 360 Bridge, Austin, TX

Barton Creek drains more than 120 square miles of mostly undeveloped terrain in the Texas Hill Country from the headwaters in Hays County to the confluence with the Colorado River in Austin (City of Austin, 1996). Almost two-thirds of the watershed lies within Travis County. Barton Creek extends over a length of 48 miles (COA, 1996). The geologic characteristics of the Barton Creek Watershed consist of an upper and lower portion separated by the Mount Bonnell Fault. The project site is located within the lower portion of the watershed that is situated on Edwards Limestone, which is characterized as karst formation.

Water quality in Barton Creek is a sensitive environmental issue among the local population. Barton Creek is dammed a few hundred feet upstream of the confluence with the Colorado River to capture water for Barton Springs Pool, which is a popular swimming facility. Barton Springs is the only known location of the Barton Springs salamander; therefore, the quality and quantity of the water at Barton Springs is related to the water quality and flow of Barton Creek (Bio-West, 2002).

About 11 % of the Barton Creek watershed was developed as of August 1996. The majority of this development occurred over a 6,500 acre area in the lower potion of the basin, adjacent to downtown Austin. In 1992, the City of Austin's Planning Department estimated impervious cover northwest of Loop 360 to be 5.5 %. The impervious cover in the watershed including the developed area south of Loop 360 is approximately 6.2 % (COA, 1996).

3.1.4 Meteorological Description

The average annual rainfall in Austin, TX is 34.72 inches (88.19 cm) based on a 30-year period of data. These data were collected at Austin-Bergstrom International Airport (formerly Bergstrom AFB) by the National Oceanic and Atmospheric Association (NOAA). Austin-Bergstrom International Airport is located 6.11 miles to the east of the project site. Historically, the wettest month in Austin is May and the driest month is February. The highest recorded rainfall in a single year was 52.2 inches in 1991 and the lowest annual rainfall was 11.4 inches in 1954 (NOAA, 2004). Snowfall is rare in the Austin area; therefore highway de-icing is rare. The average temperature for the area is 79.5 ^{o}F (26.4 ^{o}C) (NOAA, 2004).

3.2 Site Setup

Runoff flow was measured at the bridge site with a 0.5-foot, trapezoidal H-flume constructed of molded fiberglass and an area-velocity meter that was installed at the approach highway site. The rational method was implemented to size the H-flume for the 2-year return frequency storm based on the intensity-duration-frequency curves for the City of Austin. The selected storm duration was 15 minutes based on an estimate of the time of concentration of the bridge catchment. The resulting rainfall intensity was 4.6 in/hr. This rainfall intensity, duration and estimated catchment area result in a runoff flow rate of 0.25 cfs (7.1 L/s). Manufacturer performance data indicate that a 0.5-foot H-flume can accommodate a flow of 0.331 cfs (9.4 L/s) without overtopping. The selection of the 0.5 foot H-flume provides a safety factor of 1.3 of the design storm assuming that 100% of the rainfall runs off. Pool depth in the flume and accompanying flow were measured by an ISCO ® 4230 bubbler flow meter. Bubbler flow meters measure the air pressure required to push a bubble through an orifice at the bottom of the level pool to determine the depth of water in the control section of the flume. The rate of flow that corresponds to the calculated depth is generated from the stage/discharge relationship provided by the manufacturer. The flume was supported by threaded rod that was anchored in concrete in order to assure the level orientation of the flume that is required for accurate flow measurement. A photo of the flume installation at the bridge site is shown in Figure 6.

Figure 6   H-Flume Installation at the Loop 360 Bridge Site, Austin, TX

An ISCO ® 3700 series automatic sampler was used to collect flow weighted composite samples of bridge runoff. A specially designed stainless steel sample strainer was installed in the approach channel of the H-flume to prevent clogging of the intake tube by sediment and debris that could interfere with sampling the runoff. The monitoring equipment was stored in a 3-foot x 5-foot steel security box. Metal conduit was used to convey all tubing from the flume to the sampler to minimize the chances of vandalism or incidental damage. A 12-volt marine battery that was charged by a Solartec® solar module served as a power source for the equipment. Power regulating devices (dampers) were used to prevent overcharging and premature discharge of the battery.

The runoff was measured at the approach highway using an ISCO ® 4250 area-velocity meter. This flow measuring device was selected because the approach highway sample point is in a concrete culvert immediately upstream from an extended detention/sand filtration BMP. Backwater effects may occur upstream of the ponds during large storm events. The area-velocity meter is not affected by backwater effects. The ISCO ® 4250 uses a pressure transducer to gauge depth above the probe and a Doppler anemometer to measure the velocity of particles past the probe. An ISCO ® 3700 automatic sampler, identical to the one installed at the bridge site, was used to collect flow-weighted composite samples of runoff from the approach highway. The probe cable and sampler tube were run through metal conduit to the 3-foot x 5-foot security box that contained the sampler and data collection equipment. The area-velocity meter and accompanying automatic sampler can be seen mounted in the security box in Figure 7.

Figure 7 ISCO 4250 A-V Meter and 3700 Sampler installed at the Approach Highway Site, Austin, TX

A sample strainer and power supply arrangement similar to that used at the bridge site was installed at the approach highway site. The area-velocity probe was anchored to a low profile galvanized metal base plate to withstand the high shear forces resulting from the water velocity through the culvert during large runoff flows from high rainfall events. The base plate was attached to the bottom of the culvert using 5/16” Tapcon® epoxy coated concrete anchors. The sample strainer was mounted normal to the direction of flow immediately adjacent to the area-velocity probe. The sample strainer, area-velocity probe, and base plate installation are shown in Figure 8.

Figure 8 Sample Strainer, A-V Probe, and Base Plate Installation in Culvert at the Approach Highway Site, Austin, TX

An ISCO® 674 tipping-bucket rain gage was anchored to a concrete retaining wall next to the inflow box culvert at the approach highway site.

3.3 Equipment Programming

3.3.1   Flow meter Programming

The first step in programming the flow and rainfall measuring equipment was assignment of partitions in the memory banks of the flow meters for each of the measured parameters. The parameters that were logged by the flow meter are rainfall (in mm), depth of runoff (in mm), velocity (m/s), and flow (L/s). A reading of each of these parameters was generated every 5 minutes throughout the entirety of the study period.

The ISCO ® flow meters have enough memory to record measurements for approximately 1 month with no data loss. The meter begins overwriting the earliest of the stored data after about one month, depending on the amount of data that is recorded at each 5-minute interval. This setup is called the rollover option. This configuration option was most advantageous for the purposes of this study because the chances for data loss on the front end of the monitoring period are minimized by stopping recording after the partitions are filled. A negative effect is missing storms that may occur after the partitions are filled. Frequent downloading and proper archiving of data enables both setups to perform effectively. ISCO Flowlink® database software was utilized to archive all observations.

3.3.2 Automatic Sampler Programming

The variables that need to be defined to program the ISCO® 3700 sampler are the minimum size of the design storm, the number of aliquots required to collect a representative sample, the composite sample bottle volume, and the minimum volume of sample required to perform all analyses. The EPA mandates that storms must be greater than 0.1 in (2.54 cm) to be considered for NPDES Phase I compliance monitoring. Ten aliquots were sufficient to characterize each storm. The minimum volume of sample required by LCRA Environmental Laboratory Services for complete parametric analyses was 3 L (0.79 gal). Therefore, each aliquot was set at 300 mL. The capacity of the sample bottles was 9.4 L (2.48 gal) of sample. Therefore, the maximum size storm that may be completely sampled is approximately 3 times the size of the minimum storm (9.4L/3L = 3.133). Therefore, if the minimum storm is fixed at 0.1 inches, the maximum storm would be 3.133 * 0.1 inches = 0.313 inches. This relationship suggests that larger minimum storm sizes lead to wider sampling ranges, which is desirable given the wide variability of rainfall events in Central Texas. The average rainstorm in Austin, Texas is 0.7 inches (Minton, 2002). This value depends on the definition of discrete storm events (i.e. the length of the antecedent dry period that distinguishes one storm from another). The minimum storm size that was selected was 0.25 inches (6.35 mm). The largest storm that may be completely sampled without changing bottles is 0.78 inches (19.8 mm). This range simultaneously accommodates:

1) the sampling of small events
2) total sampling of the average event
3) minimizing the omission of samples during large events

3.3.3 Sampler Pacing

One goal of this study was the collection of the most representative samples as practically possible. Therefore, flow-weighted composite samples were chosen. The automatic samplers were enabled when a specified water level condition is met. The bridge sampler was enabled when depth of water sensed in the flume was 0.5 inches (12.7 mm). The approach highway sampler was triggered when the depth of water recorded in the culvert was 1 inch (25.4 mm). Once the samplers were enabled, the equipment remained enabled until the unit was reset upon retrieval of the composite samples. The ISCO® 3700 samplers automatically sample when enabled; therefore, large numbers of samples may be taken regardless of the water level fluctuations. This approach could lead to a sample that is not flow weighted, and therefore not representative of the storm event. This shortcoming was overcome by pacing the samplers.

Runoff volume was used to pace the samplers for the bridge and approach highway sites. A signal is sent to the sampler every time a selected volume of water passes the sample point. The methodology that was chosen to input the initial pacing volume for the approach highway site is shown by the following calculation which is based on the volume of runoff generated by minimum size storm that fell uniformly over the catchment with an impervious coefficient of 0.95.

Estimated catchment area = 250,500 ft^2 (23,270 m^2)

250,500 ft^2 (0.25 inch of rainfall) (1 foot/12inch) (0.95) = 4958 ft^3 (140,395 L)

4958 ft^3 / 10 aliquots = **495.8 ft^3 (14,040 L)** per aliquot = initial sample pacing

The same method was utilized to obtain the sample pacing for the bridge site. The only difference was the estimated catchment area. This initial estimate was low as a result of uncertainties associated with the runoff coefficient and catchment area. A value of 6.9 ft^3 (195 L) was used for the bridge site, and a value of 636 ft^3 (18,000 L) was used to pace the approach highway sampler. These figures were decided upon after examination of the hydrographs generated by the first 2 rainfall events. The samples from these two events were not analyzed.

3.4 Analytical Procedures

All runoff samples were delivered to Environmental Laboratory Services immediately after collection when laboratory operating hours permitted for analyses. When it was not possible to drop off the samples immediately after collection, the bottles were refrigerated at approximately 39 ^{o}F (4 ^{o}C) until the lab opened for business. All applicable QA/QC procedures were followed for the 12-month sampling period. The parameters for which the samples were analyzed were recommended by TxDOT and approved by the TCEQ. These parameters are listed in Table 1.

Table 1 Water Quality Parameters That Were Monitored

Parameter	Units	Method	Practical Quantification Limit
Copper, Total	µg/L	E200.8	1
Copper, Dissolved	µg/L	E200.8	1
Lead, Total	µg/L	E200.8	1
Lead, Dissolved	µg/L	E200.8	1
Zinc, Total	µg/L	E200.8	5
Zinc, Dissolved	µg/L	E200.8	4
Nitrogen, Nitrate (As N)	mg/L	E300	0.01
Nitrogen, Kjeldahl, Total	mg/L	E351.2	0.02
Chemical Oxygen Demand	mg/L	E410.4	7
Phosphorus, Total (As P)	mg/L	E365.4	0.04
Phosphorus, Dissolved (As P)	mg/L	E365.4	0.04
Total Suspended Solids	mg/L	E160.2	1
Volatile Suspended Solids	mg/L	E160.4	1
Fecal Coliform	cfu/100 Ml	M9222D	---
Oil & Grease, Total Recoverable	mg/L	E1664	2.58 – 2.74

Total volatile solids (TVS) were measured in lieu of volatile suspended solids (VSS) for the first 3 storm events. VSS is a more appropriate test for the purposes of this project. Therefore, the 3 samples were analyzed for VSS after the recommended hold times had expired. Grab samples were collected in specified sterile containers that are required for fecal coliform analyses and others in amber glass bottles that are specified for oil and grease samples. Four grab samples were collected throughout the monitoring period for fecal coliform and oil and grease analyses.

3.5 Statistical Analysis

The analytical results for each sample were inspected to ensure all appropriate QA/QC procedures were followed by the contracted laboratory. The data were compiled and inspected visually as well as statistically. Box plots were constructed for all runoff constituents at each site to initially characterize the data and identify potential outliers. Only one outlier was deleted from the entire data set. This outlier was the Total Kjeldahl Nitrogen (TKN) measurement for the sample collected at the approach highway site on 8-10-03. The concentration was more than eleven standard deviations above the mean, which clearly qualifies it as an outlier. The Ryan-Joiner normality test was employed to distinguish normal data sets from non-normal data sets. Overall, the data were distributed normally, but several exceptions were identified where the observed data demonstrated skewed distributions. A paired t-test was the planned hypothesis test; therefore the differences between the bridge and approach highway sites were calculated for each parameter for each storm event. These differences were subjected to the Ryan-Joiner test for normality. All differences, with the exception of nitrate-nitrogen (NO_3-N), were found to be distributed normally at a significance level of 95% (alpha = 0.05). This strong tendency toward normal distribution of data lends further credence to the selection of the paired t-test as the appropriate statistical treatment.

The null hypothesis (H_o) selected for the paired t-tests was:

Approach Highway Concentration (mg/L) – Bridge Concentration (mg/L) = 0

The alternative hypothesis (H_a) for the paired t-tests was:

Approach Highway Concentration (mg/L) – Bridge Concentration (mg/L) ≠ 0

A significance level of 95% was used for these tests. If the alternative hypothesis was acceptable at an alpha level of 0.05, the sign of the difference was inspected to determine whether the data at the bridge demonstrated significantly higher or significantly lower concentrations than the data at the approach highway. If the difference was positive, the bridge concentration was less, and conversely, if the difference was negative, the bridge concentration was greater. The alternative hypothesis for each parameter therefore is positively directional, with respect to the bridge.

Minitab, a commercially available statistics program, was used to perform the paired t-tests between the bridge and approach highway sites. Minitab calculates the statistical significance associated with each t-test in the form of a p-value. These p-values can be thought of as the "alpha level" or the chance of committing a Type 1 statistical error. A Type 1 statistical error occurs when the null hypothesis is incorrectly rejected. An alpha level of 0.05 is acceptable for most natural science and engineering applications. Therefore, for each t-test completed for each constituent of runoff (a total of 15) there is a 95% certainty that the null hypothesis of no significant difference between the concentration in the bridge runoff and in the approach highway runoff was not incorrectly rejected.

CHAPTER 4 RESULTS

4.1 Rainfall, Flow, and Volume Measurements

Volumetric flow rates were measured continuously at five-minute intervals using ISCO® flow meters throughout the sampling period. Runoff volumes were calculated for each five-minute interval using the following relationship:

$$\text{Volume}_{(5\text{ min.})} = \text{Flow Rate (L/s)} * 300\text{ s}$$

The resulting five-minute volumes were added over the length of the rainfall event to calculate total runoff volume. Rainfall was recorded at five-minute intervals throughout the monitoring period using a tipping bucket rain gauge which was connected to the flow meter at the approach highway site for data logging purposes. The flow meters were interrogated using a laptop computer shortly after each rainfall event to ensure that no data were lost or overwritten The rainfall, peak flow, and runoff data for each storm that was sampled for this project are summarized in Table 2 and Table 3.

These data indicate the size of the entire storm events, and do not isolate the portion of the storm that was sampled. For instance, storm #11 at the approach highway on 1-16-04 totaled over 2.3 inches of rain. It is not possible to completely sample an event of this magnitude without replacing the composite sample bottles mid-storm and mixing the samples at the lab to obtain a true EMC (see Methods and Materials chapter). This shortcoming is mitigated by the fact that the rainfall depths for most of the storms sampled was less than 1-inch of rain. Therefore, the preponderance of the rainfall events was within the selected effective sampling range. The concentrations reported for larger storms overestimate the actual EMCs because the runoff flow that occurs late in the storm event typically has a lower concentration of most stormwater constituents than those observed at the beginning of the storm; however, the runoff at the end of the storm is not sampled for the largest storms.

Table 2 Summary of Rainfall and Runoff Data for the Bridge Site, Loop 360, Austin, TX

Storm/Sample Number	Storm/Sample Date	Total Rainfall		Total Runoff Volume		% of Storm Sampled	Peak Flow Rate	
	mm/dd/yy	in	mm	ft^3	m^3	%	ft^3/s	m^3/s
1	06/04/03	0.66	16.8	156.8	4.44	100	0.067	0.0019
2	06/05/03	1.01	25.7	176.9	5.01	93.6	0.127	0.0036
3	06/13/03	1.36	34.5	204.4	5.79	81	0.162	0.0046
4	07/06/03	0.07	1.8	31.8	0.90	100	0.032	0.0009
5	07/08/03	0.40	10.2	69.9	1.98	100	0.060	0.0017
6	07/16/03	0.37	9.4	71.0	2.01	100	0.166	0.0047
7	08/10/03	0.56	14.2	154.7	4.38	100	0.099	0.0028
8	09/12/03	1.36	34.5	253.2	7.16	65.4	0.028	0.0008
9	09/21/03	0.49	12.4	91.1	2.58	100	0.011	0.0003
10	10/09/03	0.44	11.2	67.8	1.92	100	0.042	0.0012
11	11/17/03	0.81	20.6	134.5	3.81	100	0.173	0.0049
12	01/16/04	2.37	60.2	431.1	12.20	38.4	0.092	0.0026
13	02/04/04	0.80	20.3	137.7	3.90	100	0.035	0.0010
14	02/10/04	0.87	22.1	91.1	2.58	100	0.035	0.0010

4.2 Sample Verification

Hydrographs and hyetographs were constructed with the sample aliquots overlayed to determine whether the sample was truly representative of the storm event as a preliminary QA/QC procedure. The concentrations of each composite sample were treated as EMCs; therefore, the construction and analysis of these plots is particularly important. A sample plot is presented below in Figure 9.

These plots were constructed for all rainfall events for which runoff were sampled along with rainfall events for which runoff was not sampled as a result of equipment malfunction, insufficient rainfall, or other reasons. The remainder of these plots for all sampled events are included in Appendix I.

Table 3 Summary of Rainfall and Runoff Data for the Approach Highway Site, Loop 360. Austin, TX

Storm/Sample Number	Storm/Sample Date	Total Rainfall		Total Runoff Volume		% of Storm Sampled	Peak Flow Rate	
	mm/dd/yy	in	mm	ft^3	m^3	%	ft^3/s	m^3/s
1	06/04/03	0.66	16.8	15,050	426	100	4.4	0.12
2	06/05/03	1.01	25.7	46,150	1,306	42.7	6.0	0.17
3	06/13/03	1.36	34.5	18,267	517	100	6.7	0.19
4	08/10/03	0.56	14.2	14,318	405	100	9.3	0.26
5	09/01/03	0.58	14.7	9,893	280	100	1.6	0.05
6	09/11/03	0.52	13.2	9,502	269	100	2.9	0.08
7	09/21/03	0.36	9.1	4,300	122	100	0.8	0.02
8	10/09/03	0.44	11.2	6,831	193	100	2.9	0.08
9	11/17/03	0.82	20.8	18,892	535	100	16.3	0.46
10	01/15/04	0.63	16.0	14,546	412	100	2.8	0.08
11	01/16/04	2.37	60.2	68,039	1,925	29	4.5	0.13
12	02/05/04	0.98	24.9	24,510	694	80.4	4.5	0.13
13	02/10/04	0.87	22.1	18,932	536	100	3.6	0.10
14	02/11/04	0.88	22.4	24,809	702	79.5	4.2	0.12
15	02/24/04	1.26	32.0	26,996	764	73	7.0	0.20
16	03/04/04	0.55	14.0	14,473	410	100	6.6	0.19

Inspection of these graphs allowed identification of anomalies that occurred with the sampling equipment. The rain gauge malfunctioned on 9-11-03 and 9-21-03 for short time periods and did not affect the sampler or flow meters; therefore, the samples were retained for analyses. The rainfall on 2-24-04 was very intense with peak rates of 3.5 in/hr (84 mm/hr). The massive pulse of runoff generated caused the area-velocity meter at the approach highway to fail for a period of 30 minutes. The sampler continued to function properly during this period, therefore the problem was linked to the recording of the data not initial measurements. This inference can be made because the timing of the samples corresponded with the rainfall rate. The sample was preserved since the rainfall and sampling data were retained to authenticate the timing of the aliquots. The runoff was sampled throughout the rainfall event so any concerns regarding the quality of the sample were allayed.

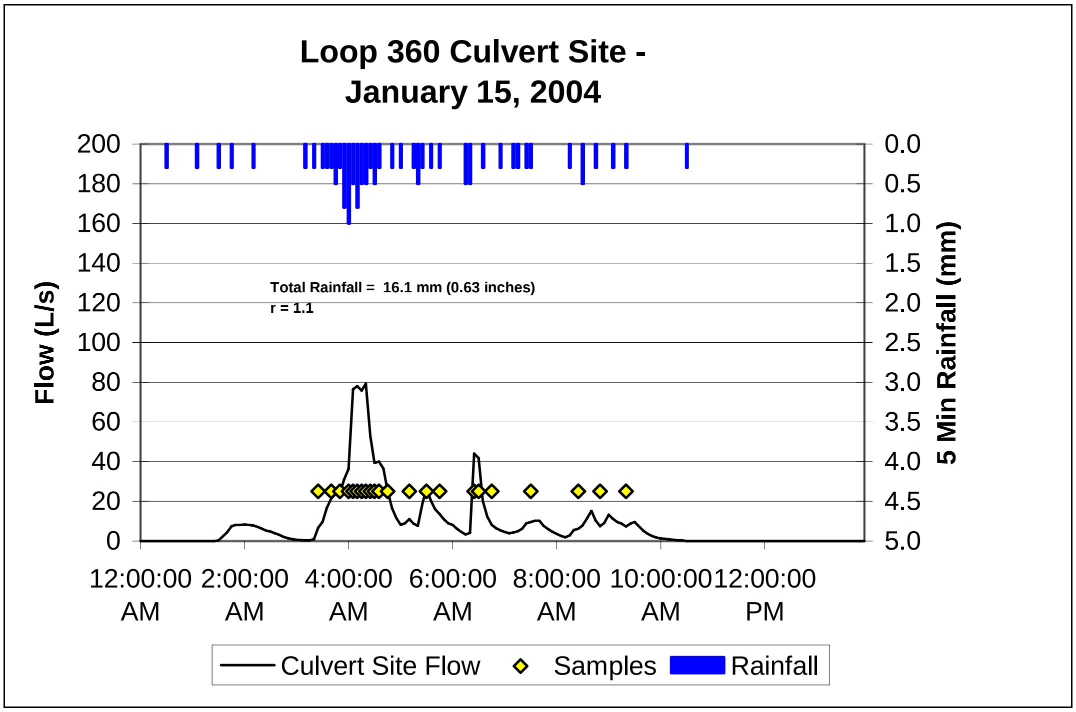

Figure 9 Example of Plots Constructed to Ensure Representative Samples

4.3 Analytical Results

Flow-weighted composite samples of bridge runoff for 15 rainfall events and composite samples of approach highway runoff from 16 rainfall events were collected throughout the course of the study. These runoff samples were analyzed for the first 14 parameters listed in Table 1. Four grab samples of runoff were collected and analyzed for fecal coliform and oil and grease concentrations for each site. The sampling effort resulted in 12 paired samples, i.e. runoff samples were collected from the bridge and the approach highway for the same rainfall event. Paired samples are required for effective null hypothesis testing. A paired test compares the difference between two samples to a reference value (usually 0 or no difference) as opposed to comparing the mean of one sample to the mean of another. A paired test is much more robust than an ordinary t-test because the variability associated with each storm event is factored out. A t-test of concentrations of a given parameter's paired samples ensures that any conclusions regarding the concentrations observed at each are a result of phenomena observed at those sites, and are not a result of differences in storm characteristics. The grab samples that were collected also were paired samples, respectively.

Average and median concentrations for each constituent in the runoff from the bridge and approach highway reported for all rainfall events that were sampled during the entire sampling period are summarized in Table 4.

Table 4 Mean and Median Concentrations of Constituents in Runoff from the Bridge and Approach Highway, at Loop 360, Austin, TX

Constituent	Units	Bridge		Highway Approach	
		Average	Median	Average	Median
Copper, Total	µg/L*	16.4	12.9	23.5	21.9
Copper, Dissolved	µg/L*	4.24	3.60	6.46	5.69
Lead, Total	µg/L*	9.93	8.90	13.1	13.7
Lead, Dissolved	µg/L*	n/a	n/a	n/a	n/a
Zinc, Total	µg/L*	167	168	135	130
Zinc, Dissolved	µg/L*	28.8	28.0	30.7	29.1
Nitrogen, Nitrate (As N)	mg/L	0.345	0.290	0.399	0.361
Nitrogen, Kjeldahl, Total	mg/L	0.970	1.03	1.54	1.29
Chemical Oxygen Demand	mg/L	33.3	24.0	56.2	50.5
Phosphorus, Total (As P)	mg/L	0.107	0.090	0.142	0.125
Phosphorus, Dissolved (As P)	mg/L	0.071	0.050	0.076	0.060
Suspended Solids - Total	mg/L	112	91.0	119	123
Suspended Solids - Volatile	mg/L	21.3	19.0	25.0	26.0
Fecal Coliform	cfu/100 mL	5550	5500	4925	4650
Oil & Grease, Total Recoverable	mg/L	4.79	4.76	6.24	5.64

* to convert to mg/L, divide µg/L by 1000 µg/mg

n/a : Indicates that there were insufficient detections of this constituent to allow for statistics to be calculated

It should be pointed out that concentrations of metals are expressed in µg/L, while the concentrations of other constituents in the runoff, e.g. nitrogen, phosphorus, suspended solids, etc. are expressed in mg/L. The reported concentrations of each constituent in the runoff from the bridge and approach highway for each rainfall event are presented in Appendix II in Table II-1 and Table II-2, respectively.

4.4 Comparison of Results with Historical Data

The average and median concentrations of constituents in runoff from the bridge and approach highway were compared with data previously reported (Irish et al., 1998; Driscoll et al, 1990). Irish et al. characterized runoff from three sections of Loop 1 (35^{th} Street, Convict Hill, and Walnut Creek) in Austin, TX. Loop 1 is a major north-south thoroughfare with traffic counts during the sampling period ranging from 16,000 vehicles/day near the outskirts of town (Convict Hill) to over 100,000 vehicles/day at West 35^{th} Street. Concentrations of nine constituents in the runoff were reported. Five parameters overlapped with those monitored in this project. Driscoll et al. (1990) reported runoff concentrations for 10 constituents, eight of which were monitored at bridges and approach highways. The data reported by Driscoll et al. (1990) are representative of national conditions. The data were collected from 31 highway sections in 11 states and at least one monitoring point was located in every geographic region in the continental United States. Highways with traffic counts of less than 30,000 vehicles per day were classified as rural; therefore, the runoff data could be separated as rural and urban. The urban runoff data from Driscoll et al. (1990) were compared to the bridge and approach highway runoff data observed in this study because of the similarity in traffic counts. Comparisons for these runoff data are presented in Table 5, which show that the concentrations of constituents in the runoff from the bridge and approach highway on Loop 360 in Austin are on the same order of magnitude, but lower than the published historical data. The Driscoll et al. (1990) data are median concentrations, while all other data are reported as average concentrations. This difference is irrelevant for the purposes of this comparison because only the central tendency of the overall data set is of concern.

Table 5 Comparison of Concentrations of Selected Constituents in Highway Runoff

Constituent	units	Loop 360 Site Austin		Irish, et al (1998)			Driscoll (1990)
		Bridge	Approach Highway	35th St	Walnut Creek	Convict Hill	
Total Suspended Solids	mg/L	115	120	190	175	120	140
Chemical Oxygen Demand	mg/L	35	55	155	95	45	118
Total Kjeldahl Nitrogen	mg/L	1	1.5	3	2.6	1.2	1.8
Total Phosphorus	mg/L	0.11	0.14	0.43	0.23	0.14	0.40
Total Zinc	mg/L	0.16	0.14	0.24	0.12	0.06	0.33

The concentrations of chemical oxygen demand, total Kjeldahl nitrogen, and total phosphorus compare well with the concentrations reported for runoff for the Convict Hill site on Mopac Blvd. This similarity indicates that the concentrations measured in the current study are characteristic of local runoff. The runoff from the bridge and approach highway exhibited consistently lower concentrations of constituents than the national median concentrations reported by Driscoll et al. (1990). Lead concentrations were excluded from this comparison since lead was removed from gasoline in the mid 1980s; therefore, comparison with historical data may be misleading. The characteristics of runoff from the bridge and approach highway observed in this project study are lower than national averages for highway runoff, but representative of the Austin area.

4.5 Comparison of Bridge Runoff Quality with Available Stream Water Quality Criteria

A comparison of the average concentrations in the bridge runoff samples to the available stream water quality criteria are presented in Table 6. These data show that none of the dissolved metals (copper, lead, and zinc) exceed the surface water quality limits for Texas. Total phosphorus and total nitrogen exceeded the proposed EPA eco-region criteria, but it is important to note that the document containing these proposed criteria stated that there is likely an error in the total phosphorus criterion (USEPA, 2002). Therefore, the proposed criteria should be used with caution. The average fecal coliform count exceeds the water quality standard recommended for the protection of beneficial uses in Barton Creek.

Table 6 Comparison of Bridge Data to Available Criteria

Constituent	Number of Samples	Average	Median	Criteria*
Copper, Total, µg/L	15	16.42	12.9	
Copper, Dissolved, µg/L	15	4.24	3.6	**19.33**
Lead, Total, µg/L	15	9.93	8.9	
Lead, Dissolved, µg/L	15	ND	ND	**4.95**
Zinc, Total, µg/L	15	166.5	168	
Zinc, Dissolved, µg/L	15	28.83	28	**163.83**
Nitrate, as N, mg/L	15	0.34	0.29	
TKN, mg/L	15	0.97	1.03	
Total N, mg/L	15	1.32	1.35	**0.76**
COD, mg/L	15	33.33	24	
Phosphorus, Total, mg/L	15	0.11	0.11	**0.13**[**]
Phosphorus, Dissolved, mg/L	15	0.08	0.06	
TSS, mg/L	15	111.8	91	
VSS, mg/L	15	22.58	20	
Fecal Coliform, cfu/100 mL	3	5067	4000	**400**[a]
Oil & Grease, TR, mg/L	3	4.24	4.71	

*: From Texas Surface Water Quality Standards, TAC Chapter 307.6 (c) (8), (2000), and EPA Proposed Eco region criteria, (2002). www.epa.gov/waterscience/criteria/nutrient/strategy.html

[**]: This value appears inordinately high and may either be a statistical anomaly or reflects a unique condition. In any case, further investigation is indicated to determine the sources of error.

[a]: Water Quality Standard designated for the Protection of Beneficial Uses in Barton Creek

4.6 Hypothesis Testing of the Data

The 12 paired samples were subjected to hypothesis testing to determine any statistically significant difference between the concentration of a constituent of the bridge deck runoff and that of the approach highway runoff. The diagnostic procedures are outlined in Section 3.5. The results of these statistical analyses are presented in Table 7. Note that all of the listed differences for the confidence intervals are positive, indicating that the concentrations were either significantly higher at the approach highway or statistically equal.

No instance occurred in which the concentration of a constituent in the bridge runoff was significantly greater than that of the approach highway. Confidence intervals were not calculated for parameters that caused acceptance of the null hypothesis. Zero would be within the confidence interval for all null tests, meaning there is a 95% chance that the difference between the bridge and approach highway is zero. When the null hypothesis is accepted, both the bridge and highway samples could have been drawn from the identical population or distribution.

Dissolved lead could not be analyzed in this fashion because dissolved lead was not detected in many samples of bridge and approach highway runoff. TKN was analyzed using only 11 samples, since one outlier was removed from the data set (TKN on 8-10-03).

Table 7 p-values and 95% Confidence Levels Resulting from Hypothesis Testing

Constituent	Hypothesis Accepted?	P-Value	95% Confidence Interval	Bridge Deck Concentration is:
Copper, Total	Alternative	0	6.4 - 16.6	lower
Copper, Dissolved	Alternative	0.001	1.3 - 3.6	lower
Lead, Total	Alternative	0.004	2.3 - 9.8	lower
Lead, Dissolved	Null	n/a	n/a	no difference
Zinc, Total	Null	0.681	n/a	no difference
Zinc, Dissolved	Null	0.51	n/a	no difference
Nitrogen, Nitrate (As N)	Null	0.312	n/a	no difference
Nitrogen, Kjeldahl, Total	Alternative	0.019	0.07 - 0.67	lower
Chemical Oxygen Demand	Alternative	0.007	7.0 - 34.5	lower
Phosphorus, Total (As P)	Alternative	0.031	0.006 - 0.106	lower
Phosphorus, Dissolved (As P)	Null	0.664	n/a	no difference
Suspended Solids - Total	Alternative	0.012	11.5 - 73.0	lower
Suspended Solids - Volatile	Alternative	0.001	4.8 - 13.6	lower
Fecal Coliform	Null	0.835	n/a	no difference
Oil & Grease, Total Recoverable	Null	0.663	n/a	no difference

n/a indicates that there were no statistically significant results generated for this parameter

4.7 Annual Loading Comparison

Not all storms were sampled during the course of this study and the total rainfall amount was not similar to the yearly average in Austin. Therefore, the average annual loading of each constituent from the Loop 360 bridge to Barton Creek was calculated by multiplying the average concentration of each constituent by the runoff coefficient and the average annual rainfall (inch/yr) for Austin. The runoff coefficient used was 0.95. Annual rainfall volume was obtained by multiplying the average annual rainfall for Austin, TX (34.2 in/yr or 0.87 m/yr (NOAA, 2004); by the total area of the bridge 30,000 ft^2 (2787 m^2). Loads were estimated for the entire Loop 360 bridge over Barton Creek on an annual basis, and reported in Table 8.

Table 8 Annual Loading of Constituents in Runoff from Loop 360 Bridge to Barton Creek

Constituent	Annual Load from Loop 360 Bridge		Annual Load per m^2 of Loop 360 Bridge	
	kg/yr	lb/yr	kg/yr-m^2	lb/yr-m^2
Copper, Total	0.04	0.09	1.36×10^{-5}	3×10^{-5}
Copper, Dissolved	0.01	0.02	3.51×10^{-6}	7.7×10^{-6}
Lead, Total	0.023	0.05	8.21×10^{-6}	1.8×10^{-5}
Lead, Dissolved	ND		ND	
Zinc, Total	0.38	0.84	1.38×10^{-4}	3.04×10^{-4}
Zinc, Dissolved	0.07	0.15	2.38×10^{-5}	5.24×10^{-5}
Nitrate, as N	0.79	1.74	2.85×10^{-4}	6.28×10^{-4}
TKN	2.23	4.91	8.02×10^{-4}	0.0017
Total N	3.03	6.7	1.09×10^{-3}	0.0024
COD	76.78	169.3	0.0276	0.06
Phosphorus, Total	0.26	0.57	9.27×10^{-5}	2.04×10^{-4}
Phosphorus, Dissolved	0.19	0.42	6.84×10^{-5}	1.5×10^{-5}
TSS	257.53	567.8	0.0924	0.204
VSS	52.02	114.7	0.0187	0.041
Fecal Coliform cfu/yr	1.16×10^{11}		4.16×10^{7}	
Oil & Grease, TR	9.77	21.53	0.0035	0.0077

The USGS monitoring station at Loop 360 over Barton Creek was used as the source of flow data and water quality measurements (USGS, 2004). Stream flows have been measured daily at the site since 1978 and annual average data were available on the USGS website. Annual flows recorded at the site are shown in Table 9.

The flow measurements were averaged for the period from 1978 to 2001 resulting in an average annual stream flow of 48.4 ft^3/s for Barton Creek at Loop 360. The average stream flow was divided into base flow and storm flow based on the ratio base flow:storm flow = 0.49 (City of Austin, 1996). Therefore, the average annual base flow was 23.72 ft^3/s and the average annual storm flow was 24.68 ft^3/s. The storm flow was used to estimate loading of specific constituents in Barton Creek at Loop 360, to make an accurate comparison with storm water loadings from Loop 360 bridge over Barton Creek.

Table 9 Average Annual Stream Flow for Barton Creek at Loop 360

Year	Average Stream Flow	
	ft^3/s	L/s
1978	0.036	1.02
1979	60.2	1700
1980	14.6	410
1981	111	3140
1982	11.4	320
1983	8.14	230
1984	19.8	560
1985	77.7	2200
1986	70.2	1980
1987	129	3650
1988	0.5	14
1989	20	560
1990	4.68	130
1991	104	2940
1992	157	4440
1993	20.7	580
1995	41.3	1170
1996	0.08	2
1997	94.8	2680
1998	87	2460
1999	1.78	50
2000	14.8	419
2001	64.4	1823

Water quality constituents for Barton Creek at Loop 360 have been measured by the USGS since 1978. However, composite samples were collected only since June 2000. The concentrations reported for these composite samples were used for comparison with results for the composite samples of runoff collected at the Loop 360 bridge in this study. The average base flow and storm flow concentrations for each constituent in Barton Creek are shown in Table 10.

Table 10 Average Concentrations of Water Quality Constituents in Barton Creek at Loop 360, Austin, TX

Constituent	Average Concentration at Base Flow	Average Concentration at Storm Flow
Copper, Total, μg/L	5.6	4.34
Lead, Total, μg/L	ND	6.11
Zinc, Total, μg/L	4	26.75
Nitrate, as N, mg/L	0.14	0.345
Total N, mg/L	0.35	1.825
COD, mg/L	ND	43
Phosphorus, Total, mg/L	0.02	0.25
Phosphorus, Dissolved, mg/L	ND	0.09
TSS, mg/L	12	306
VSS, mg/L		12
Fecal Coliform, cfu/100mL	135	51,383

A comparison of the average storm flow concentrations and loads in bridge runoff to those reported in Barton Creek at the Loop 360 bridge are presented in Table 11 and Table 12, respectively. A detailed table showing all composite data collected by USGS for Barton Creek at Loop 360 is included in Appendix III.

A comparison of the annual load of each constituent contributed by the Loop 360 bridge runoff to the load present in Barton Creek at Loop 360 indicates that the load contributed by the bridge runoff is several orders of magnitude less than the load in Barton Creek upstream of the bridge. Therefore, the percent increase in loading of these constituents to Barton Creek is minimal (0.056% is the greatest for total zinc). The results indicate that storm water runoff from the Loop 360 bridge does not result in any substantial adverse impact to the water quality in Barton Creek.

Table 11 Average Concentration of Water Quality Constituents in Barton Creek at Loop 360 Bridge, Austin, TX

Constituent	Average Storm Flow Concentration from Loop 360 Bridge	Average Storm Flow Concentration in Barton Creek at Loop 360
Copper, Total, µg/L	16	4
Copper, Dissolved, µg/L	4	N.A.
Lead, Total, µg/L	10	6
Lead, Dissolved, µg/L	ND	N.A.
Zinc, Total, µg/L	166	27
Zinc, Dissolved, µg/L	29	N.A.
Nitrate, as N, mg/L	0.34	0.34
TKN, mg/L	0.97	N.A.
Total N, mg/L	1.32	1.82
COD, mg/L	33	43
Phosphorus, Total, mg/L	0.11	0.26
Phosphorus, Dissolved, mg/L	0.08	0.09
TSS, mg/L	112	306
VSS, mg/L	23	12
Fecal Coliform, cfu/100mL	5067	51383
Oil & Grease, TR, mg/L	4.2	N.A.

Table 12 Comparison of Average Storm Flow Loads in Barton Creek at the Loop 360 Bridge, Austin, TX

Constituent	Annual Load Barton Creek Upstream of Loop 360 Bridge,		Annual Load Contributed by Loop 360 Bridge Runoff		% Increase
	kg/yr	lb/yr	kg/yr	lb/yr	
Copper, Total	214	472	0.04	0.09	0.018
Copper, Dissolved			0.01	0.022	
Lead, Total	135	298	0.023	0.05	0.017
Lead, Dissolved			ND		
Zinc, Total	680	1500	0.38	0.84	0.056
Zinc, Dissolved			0.07	0.15	
Nitrate, as N	10,625	23,424	0.79	1.74	0.007
TKN			2.23	4.9	
Total N	47,610	104,962	3.03	6.7	0.006
COD	9.44×10^5	2.08×10^6	76.78	170	0.0085
Phosphorus, Total	6,165	13,591	0.26	0.57	0.004
Phosphorus, Dissolved	2,148	4,735	0.19	0.42	0.008
TSS	7.0×10^6	1.54×10^7	257.53	568	0.0036
VSS	2.64×10^5	5.82×10^5	52.02	115	0.02
Fecal Coliform*	1.13×10^{16}	2.49×10^{16}	1.16×10^{11}	2.55×10^{11}	0.001
Oil & Grease, TR			9.77	21.5	

*: Units of cfu/yr

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

The purpose of this project was the characterization of the water quality of the runoff from a highway bridge and approach highway. Statistical comparisons between paired concentrations in runoff samples were used to determine to what extent bridge runoff and approach highway runoff are similar or different. These objectives are vital for understanding the environmental impacts of nonpoint source pollution from highways on the water quality of receiving water bodies. The results of this study were used to quantify the constituent loadings in the runoff from the Loop 360 bridge over Barton Creek on the water quality of Barton Creek. The current TMDL process requires any entity that contributes to water quality impairment to share in the waste load reduction that is necessary to regain the beneficial uses of the water body. Accurate monitoring data is a useful tool for quantifying waste loads from bridge and highways, especially in light of the trend toward hydrodynamic water quality models as a means for this quantification. A large amount of data exists that describes highway runoff pollutant concentrations, but little information is available regarding bridge runoff characteristics. The data presented in this report provide the highway operators with a better measurement of the quality of bridge and highway runoff that can be applied to similar sites in Central Texas to allocate waste loads in the fairest and most scientifically-based manner.

The key findings of this report based on EMCs for 15 constituents in runoff from the bridge and approach highway are:

1. The bridge runoff exhibited statistically lower concentrations of total copper, dissolved copper, total lead, COD, total phosphorus, TKN, TSS, and VSS than the approach highway.

2. There was no statistically significant difference between concentrations of total zinc, dissolved zinc, NO_3-N, dissolved phosphorus, fecal coliform, and oil and grease in the bridge runoff and approach highway runoff.

3. Highway bridge runoff did not exhibit statistically higher concentrations of pollutants than approach highway runoff.

4. No statements could be made about dissolved lead because detectable concentration of dissolved lead (above the practical quantification limit [PQL]) was not observed in a sufficient number of runoff samples to perform any of the statistical tests. However, the PQL for dissolved lead is an order of magnitude below the applicable Texas water quality standard. Therefore the observed runoff data indicate that dissolved lead is not discharged from bridges and approach highways at concentrations that could cause any appreciable degradation of surface water quality.

5. Highway runoff data could be used as a conservative proxy for bridge deck runoff for total and dissolved copper, total lead, COD, total phosphorus, TKN, TSS, and VSS if site specific data were unavailable.

6. Highway runoff data could be used as a more accurate proxy for bridge deck runoff for total zinc, dissolved zinc, NO_3-N, dissolved phosphorus, fecal coliform, and oil and grease if site specific data were unavailable.

7. The 95% confidence intervals presented in Table 7 of the Results section may be used to quantify the expected differences between bridge and highway runoff. For example, if one had a significant amount of highway data for the parameters listed in Table 7 with confidence intervals, a value within the reported confidence

interval could be subtracted from the site specific highway data to achieve a reasonable estimate of the expected bridge runoff quality.

8. The concentrations of constituents in runoff that were observed in this study were of the same order, but less than average historical highway runoff concentrations and are typical of concentrations reported for highway runoff in the Austin, TX area.

9. Storm water runoff from the Loop 360 bridge results in small changes to the concentrations and loads in Barton Creek.

10. Loading of all measured water quality constituents from the bridge deck to Barton Creek are minimal. The loads in Barton Creek upstream of the Loop 360 bridge are in most cases several orders of magnitude greater than the loads contributed by the bridge runoff. The largest increase in load of any constituent caused by bridge contributions is 0.056% for total zinc.

11. Concentrations in the bridge runoff exceeded those in Barton Creek for total metals (copper, lead, and zinc) and VSS. Water quality data was not available for Barton Creek at Loop 360 for dissolved metals, TKN, and oil and grease. The average storm flow concentrations of all the other constituents were lower at the Loop 360 bridge compared to Barton Creek.

12. None of the dissolved metals concentrations in the runoff for individual rainfall events exceeded the Texas Surface Water Quality Standards.

13. Average concentrations of total nitrogen in bridge runoff was 1.32 mg/L, compared to the proposed EPA criterion of 0.76 mg/L, and the average total phosphorus concentration in bridge runoff was 0.11 mg/L compared to the

proposed EPA criterion of 0.128 mg/L. However, it should be noted that the EPA noted that the total phosphorus criterion appeared inordinately high and may either be a statistical anomaly or reflect a unique condition.

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APPENDIX I - HYDROGRAPHS FOR SAMPLED STORM EVENTS

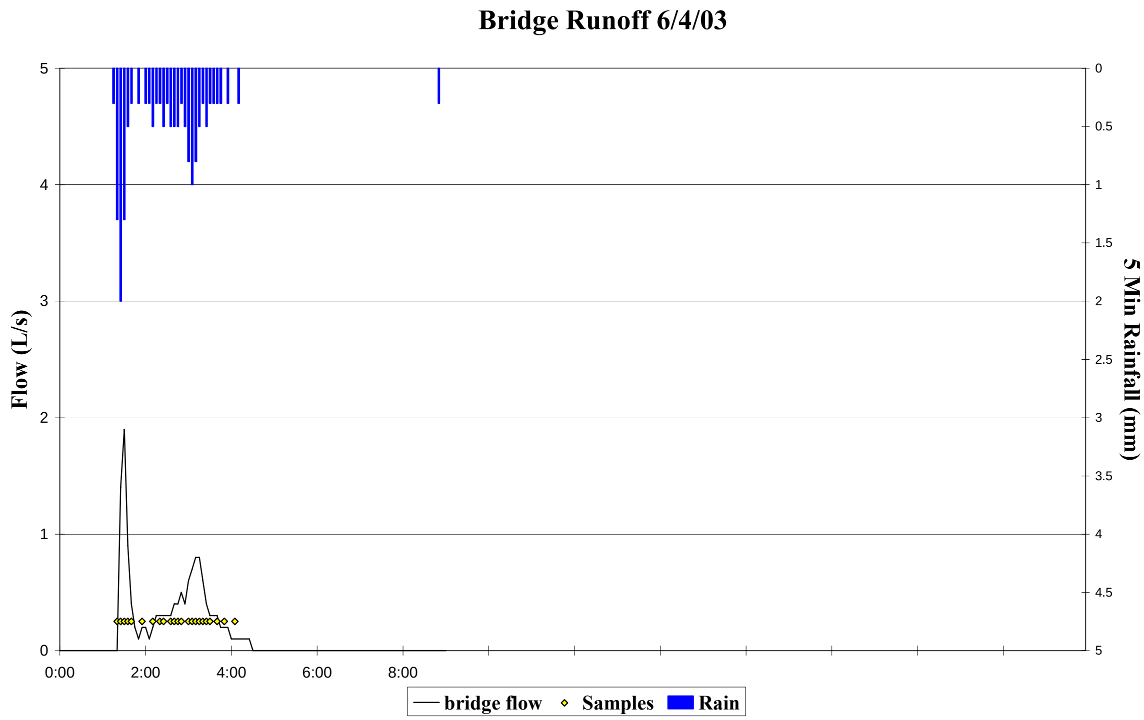

Figure I-1: Stormwater Runoff and Rainfall for Sample 1

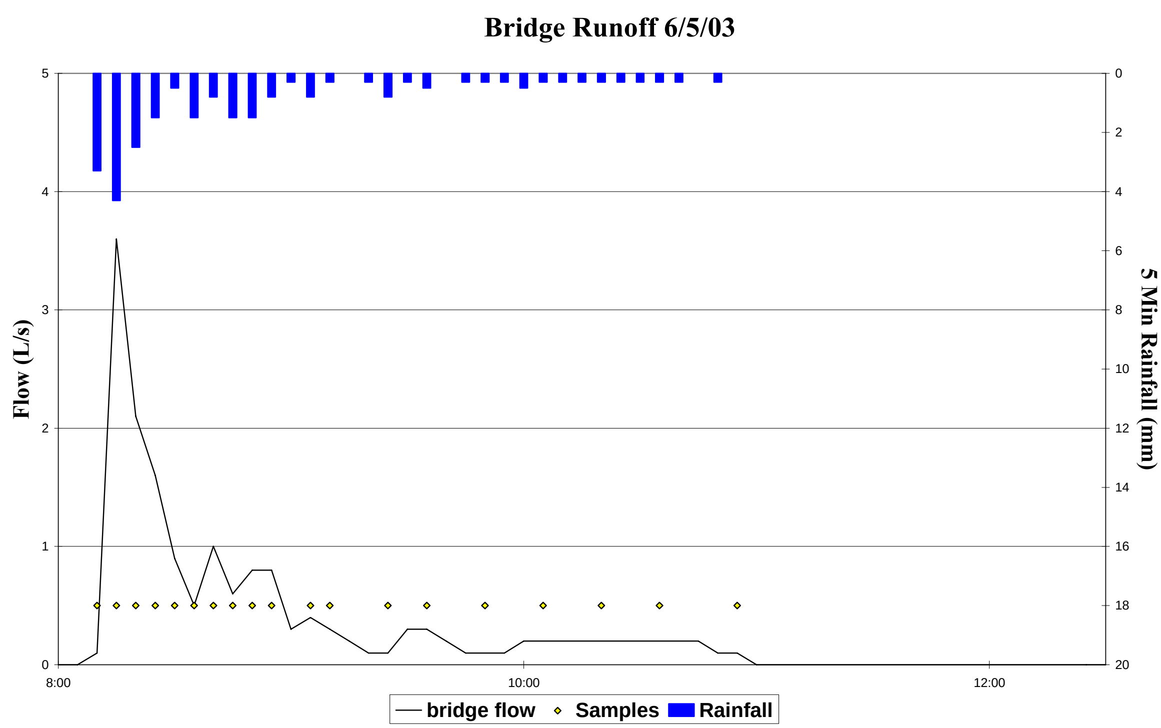

Figure I-2: Stormwater Runoff and Rainfall for Sample 2

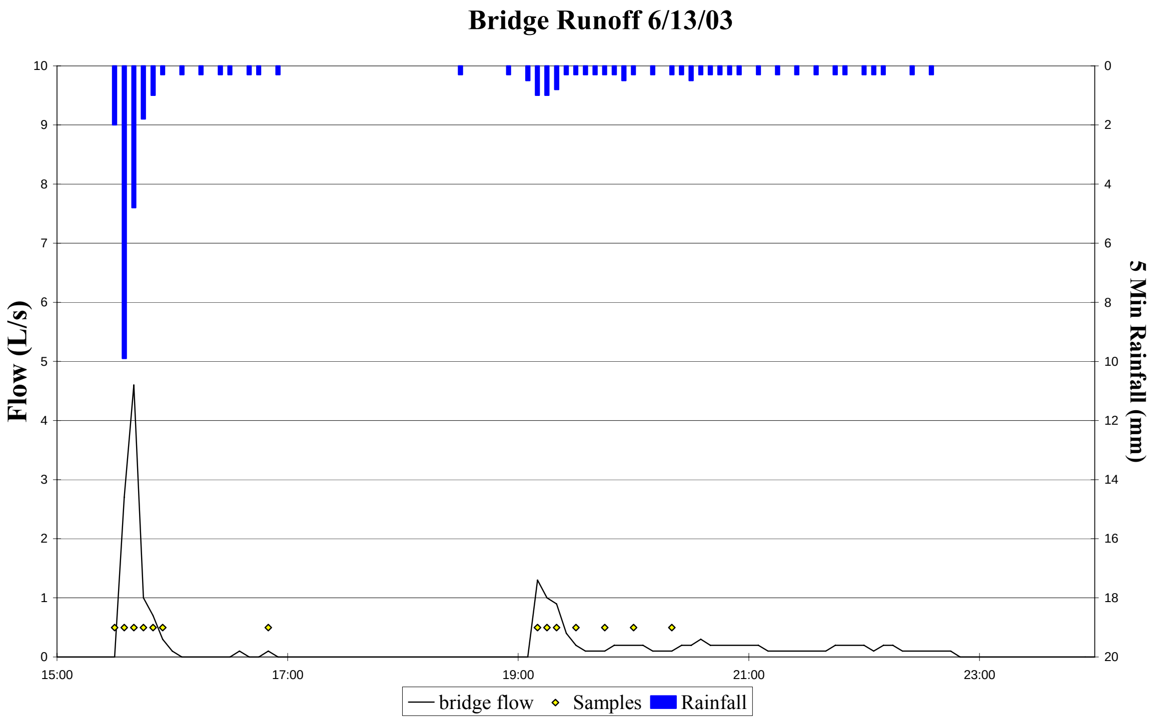

Figure I-3: Stormwater Runoff and Rainfall for Sample 3

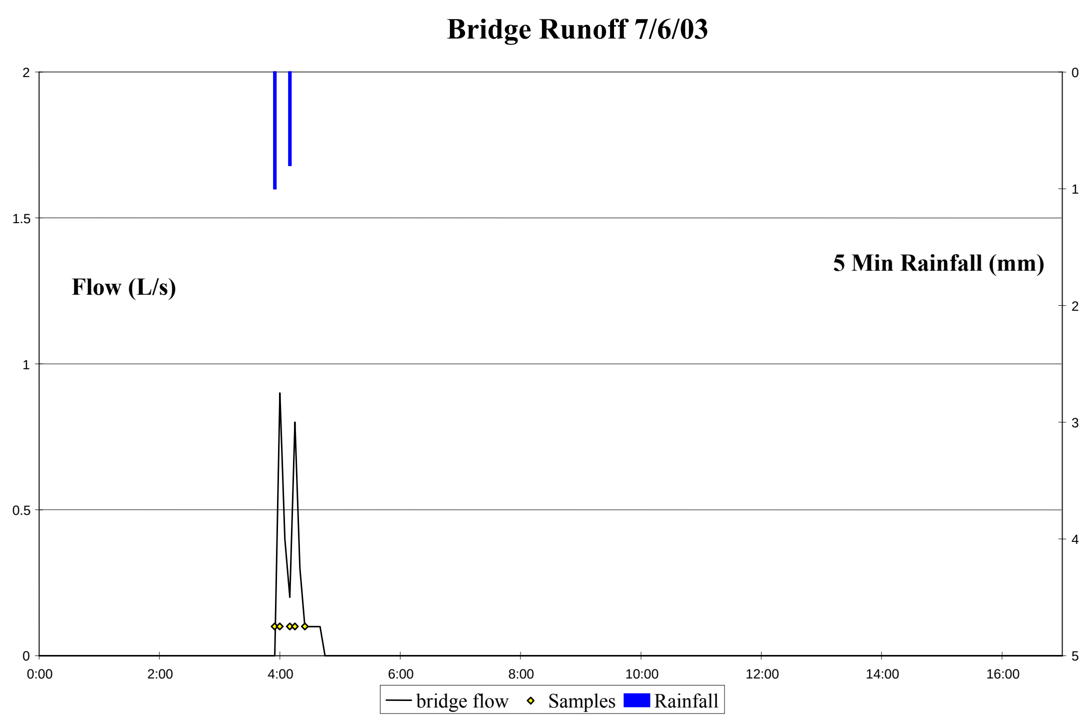

Figure I-4: Stormwater Runoff and Rainfall for Sample 4

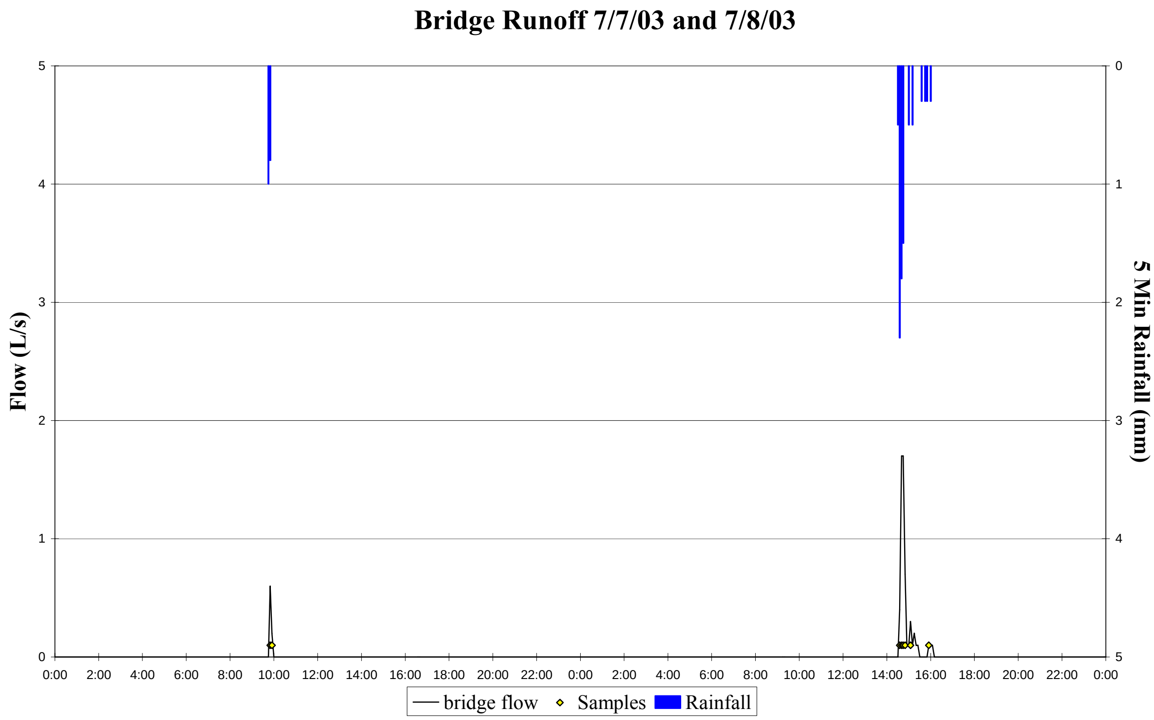

Figure I-5: Stormwater Runoff and Rainfall for Sample 5

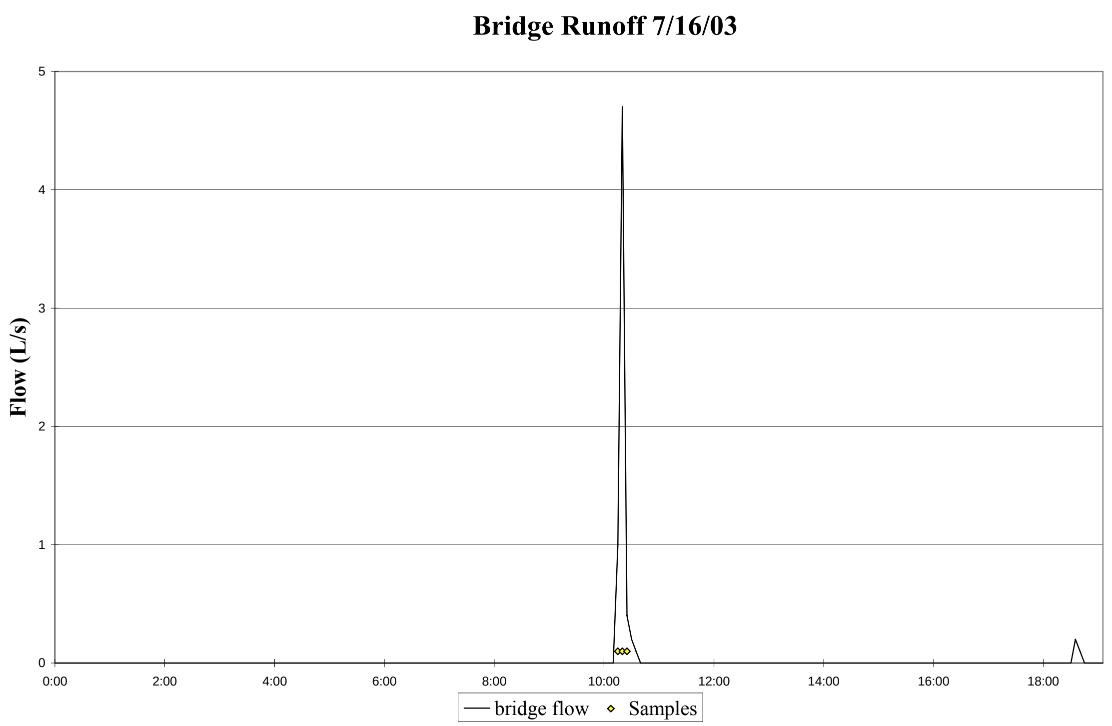

Figure I-6: Stormwater Runoff and Rainfall for Sample 6

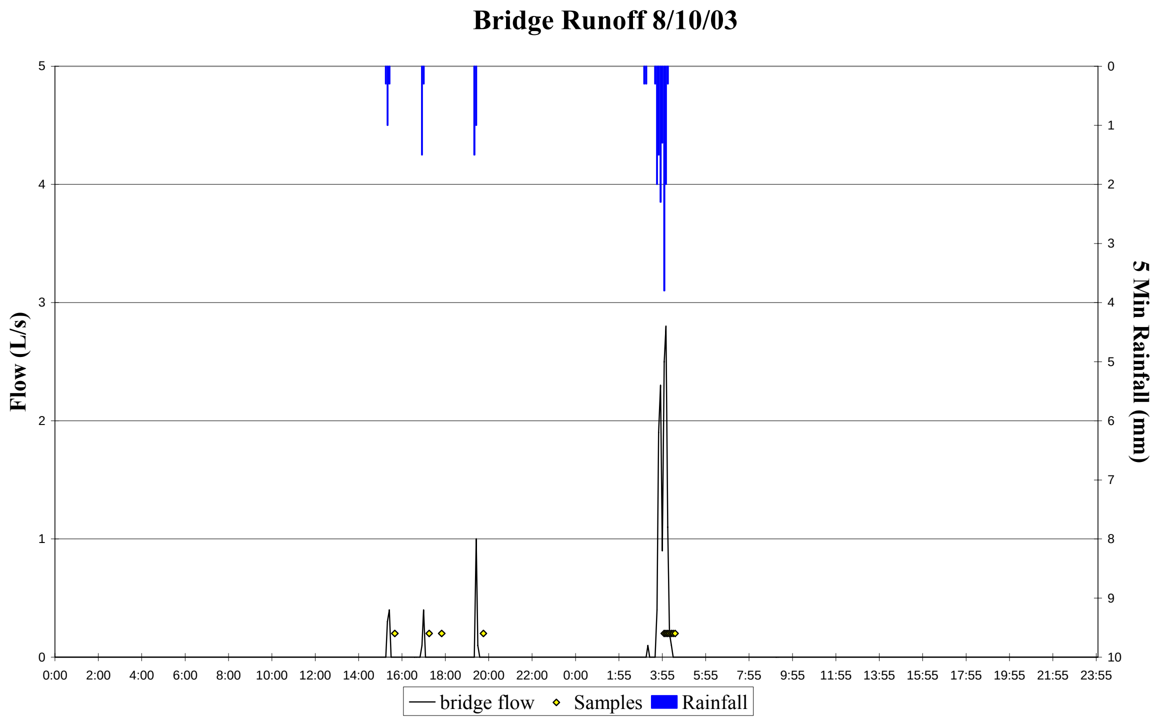

Figure I-7: Stormwater Runoff and Rainfall for Sample 7

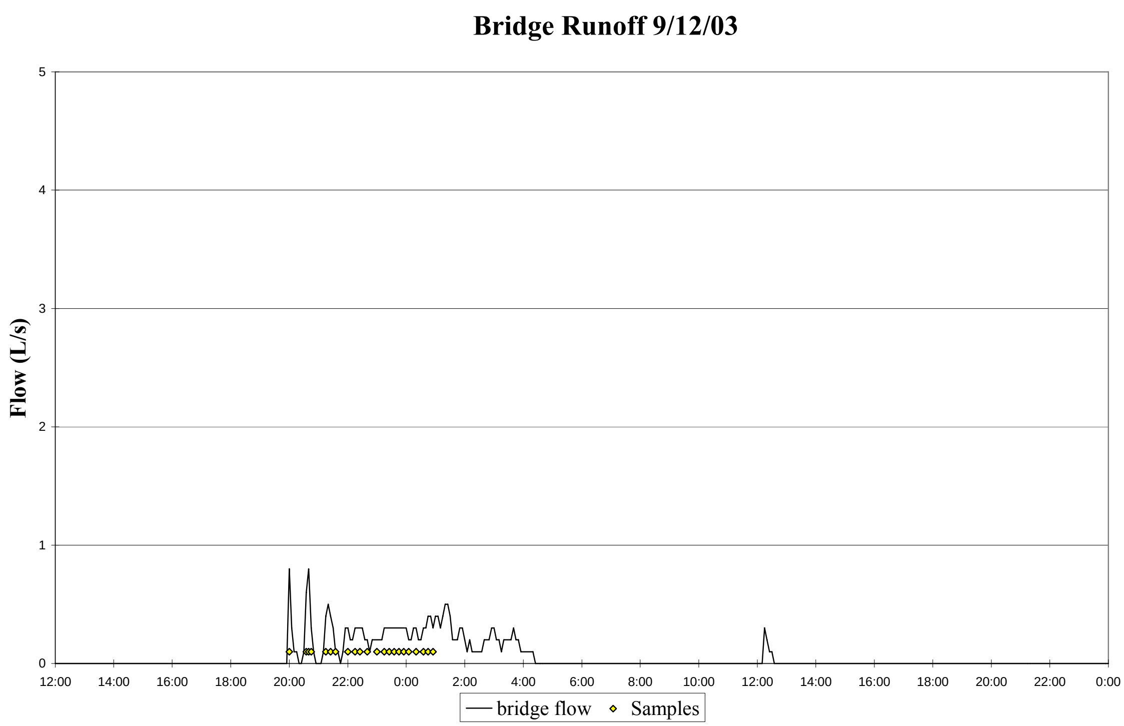

Figure I-8: Stormwater Runoff and Rainfall for Sample 8

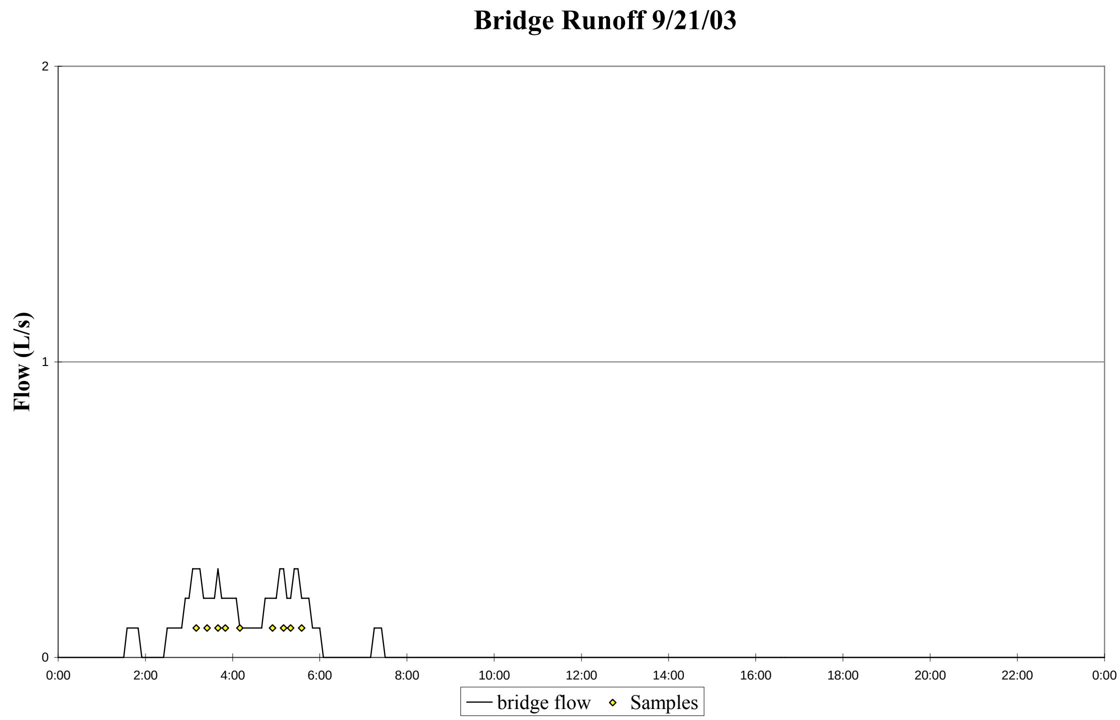

Figure I-9: Stormwater Runoff and Rainfall for Sample 9

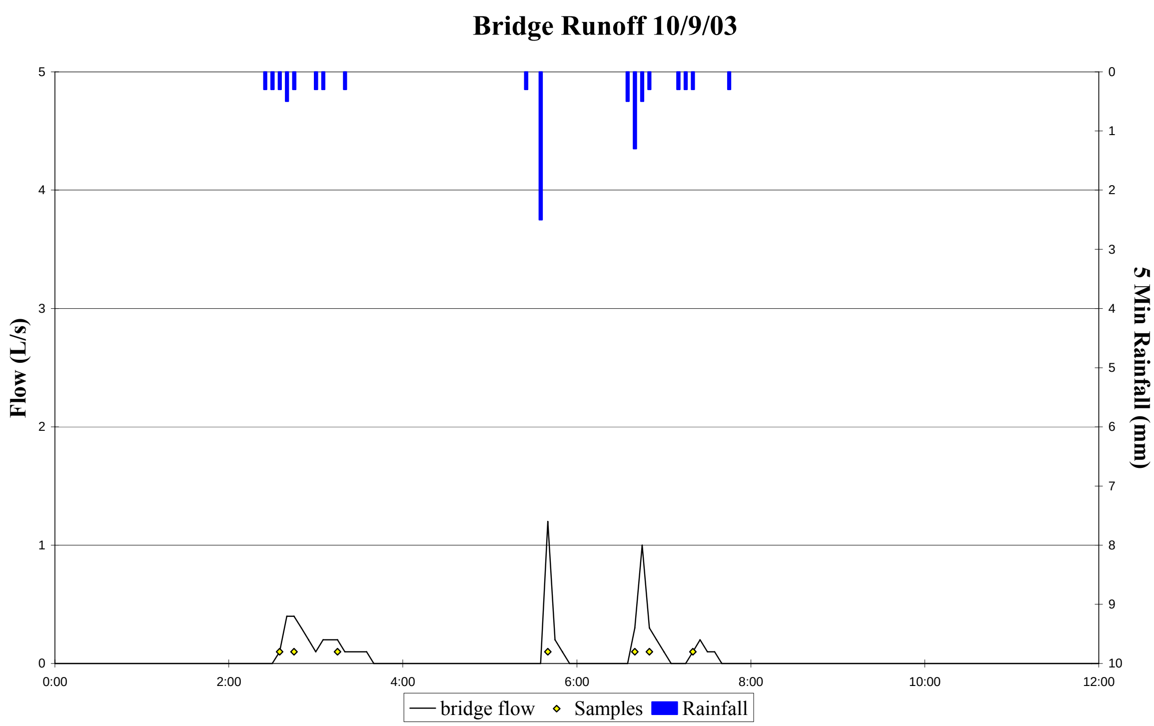

Figure I-10: Stormwater Runoff and Rainfall for Sample 10

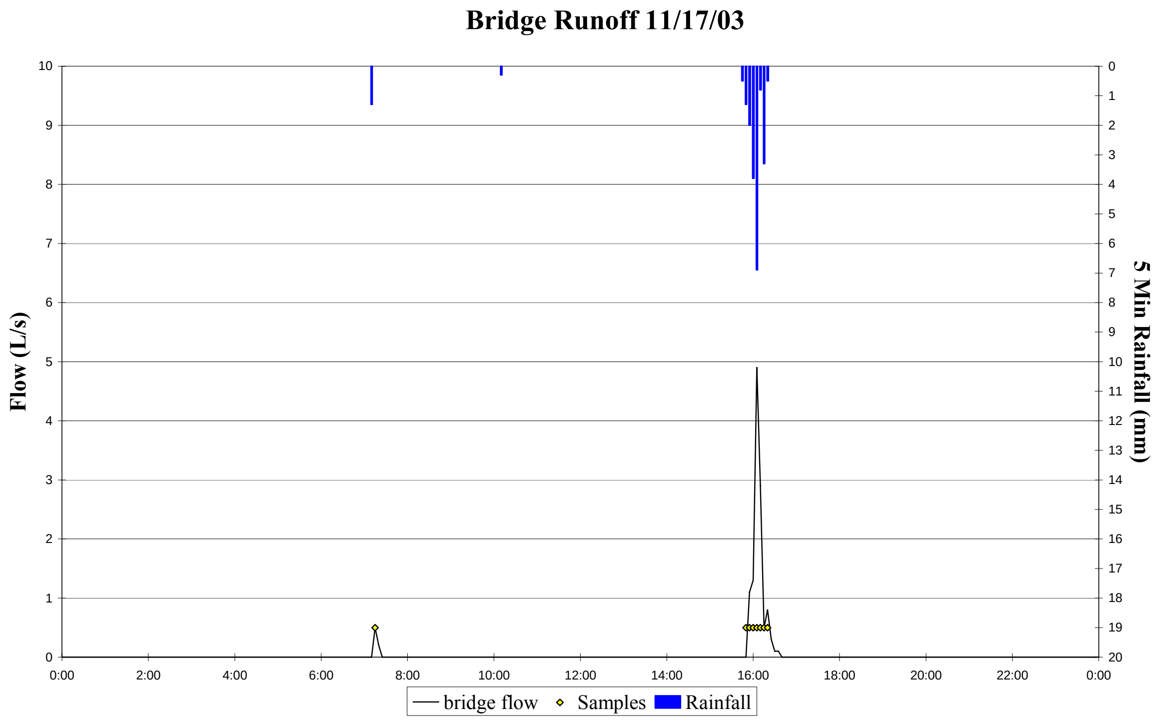

Figure I-11: Stormwater Runoff and Rainfall for Sample 11

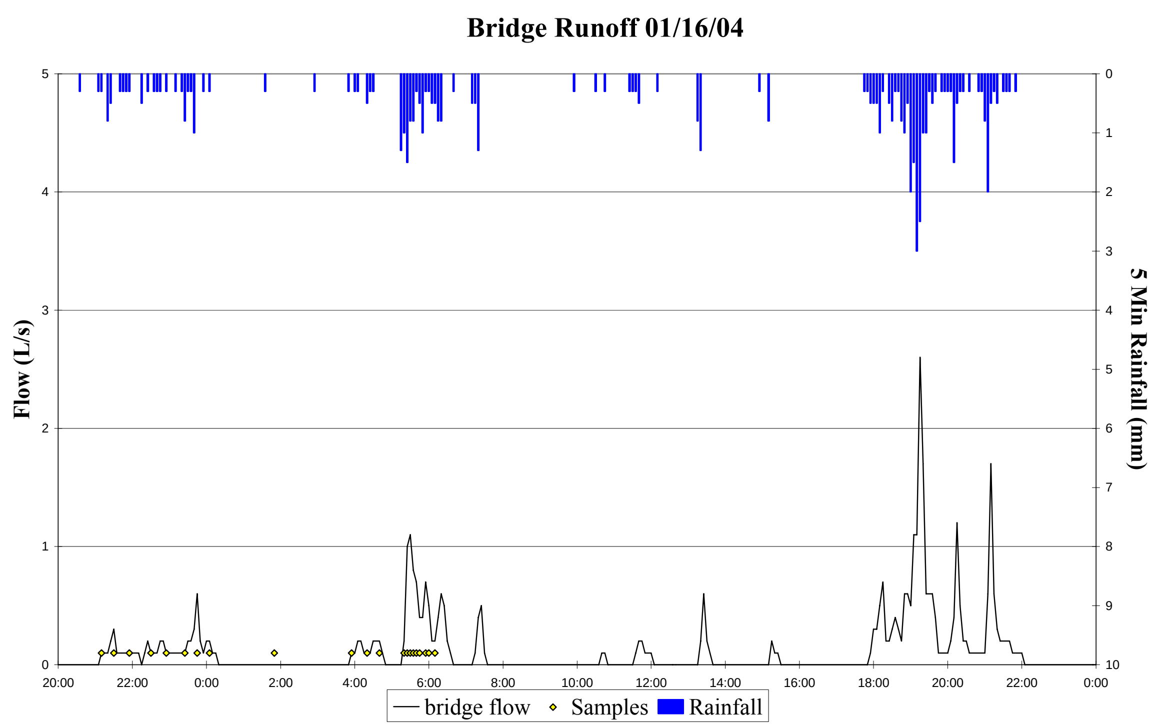

Figure I-12: Stormwater Runoff and Rainfall for Sample 12

Bridge Runoff 2/4/04

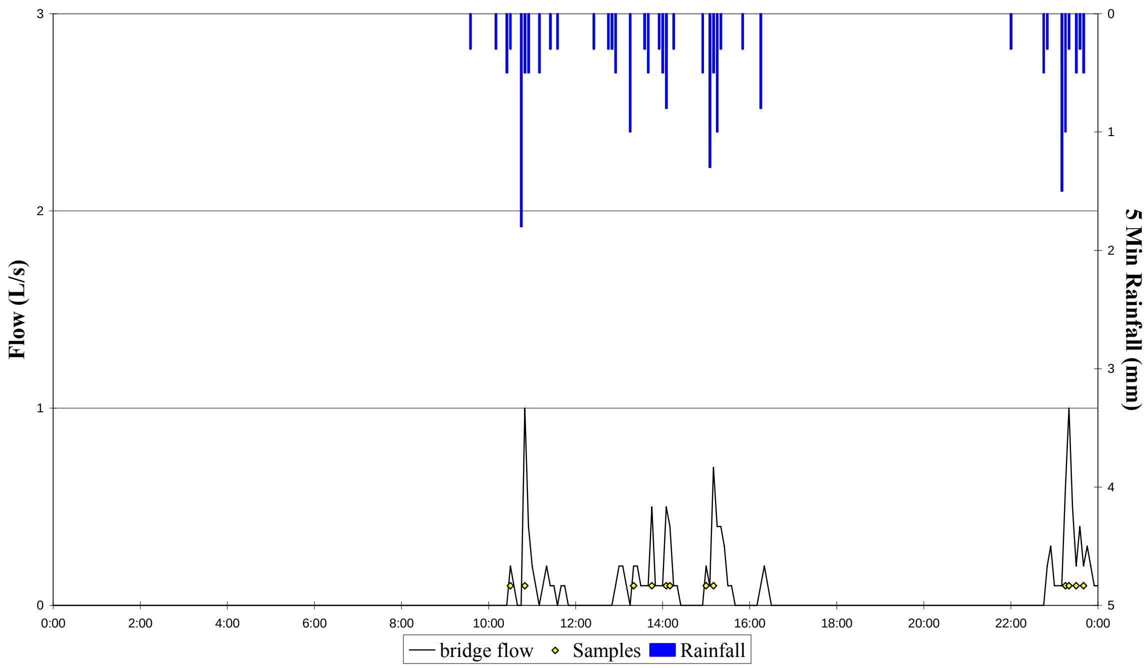

Figure I-13: Stormwater Runoff and Rainfall for Sample 13

Bridge Runoff 2/10/04

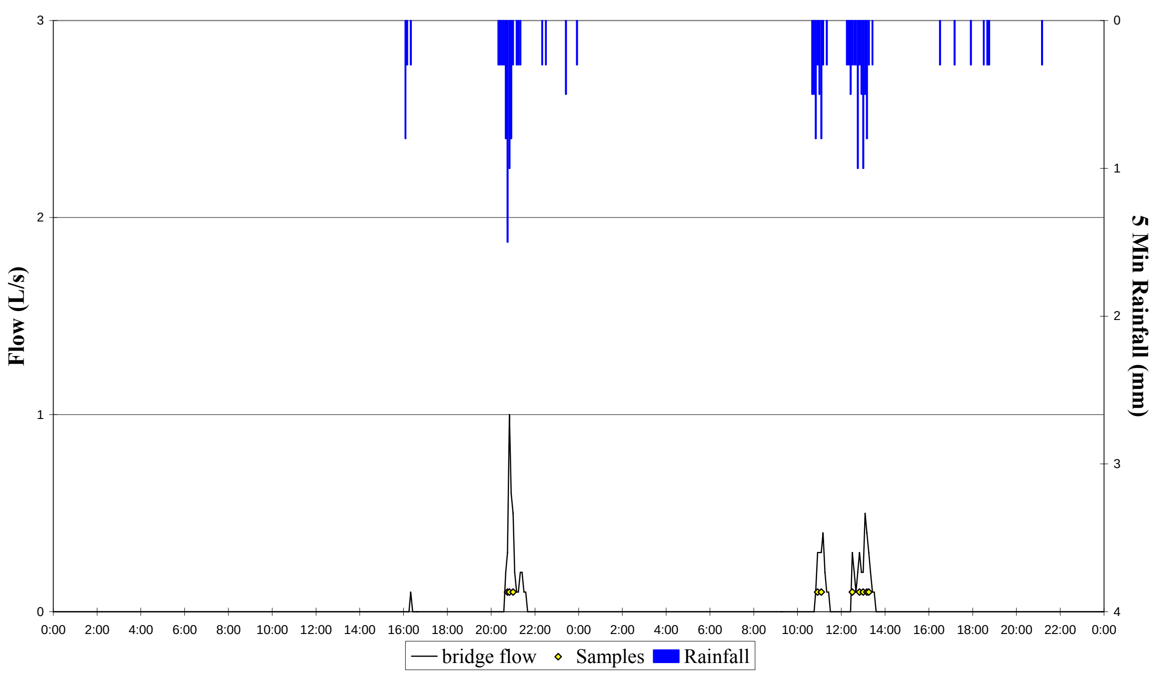

Figure I-14: Stormwater Runoff and Rainfall for Sample 14

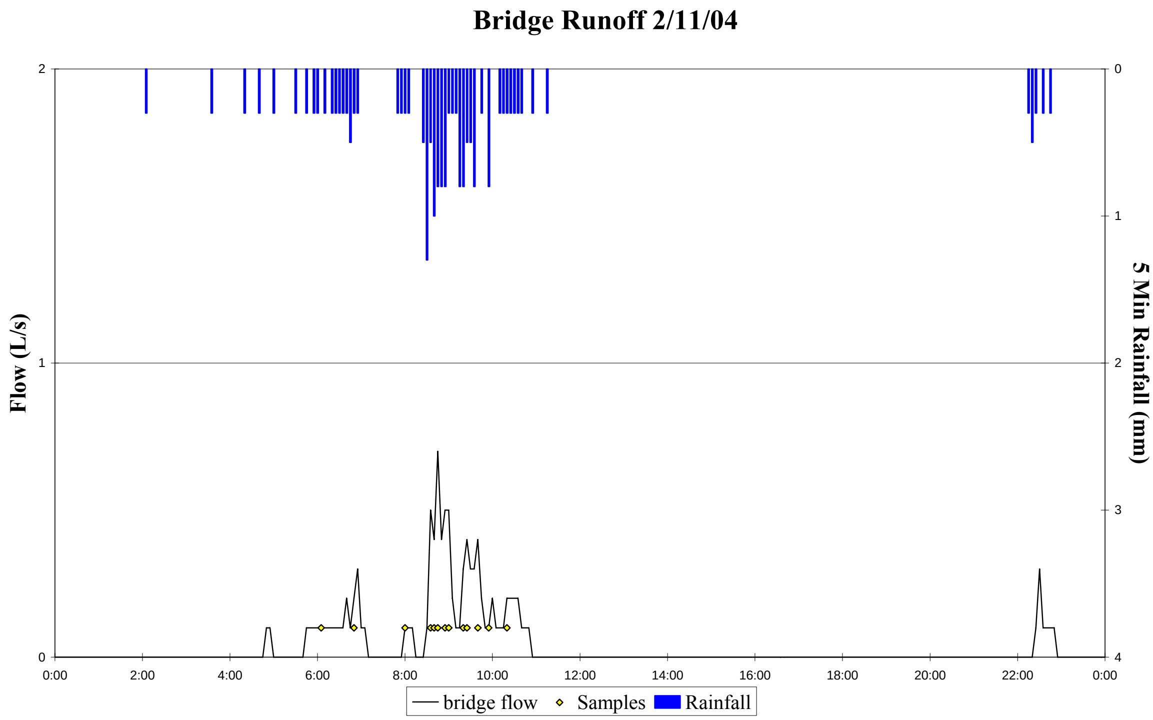

Figure I-15: Stormwater Runoff and Rainfall for Sample 15

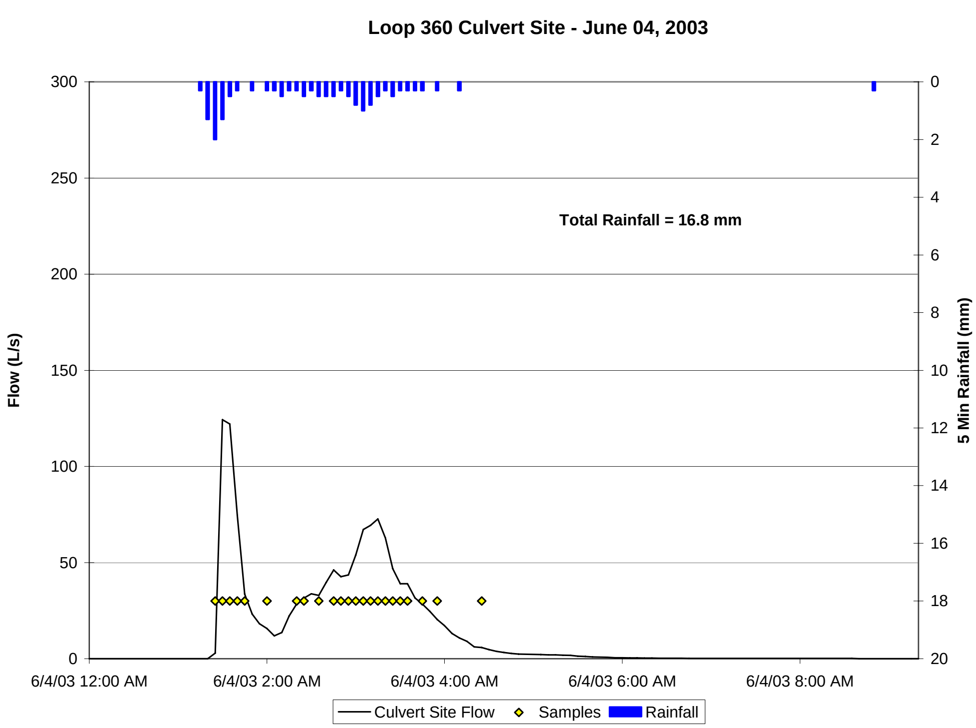

Figure I-16: Stormwater Runoff and Rainfall for Sample 1

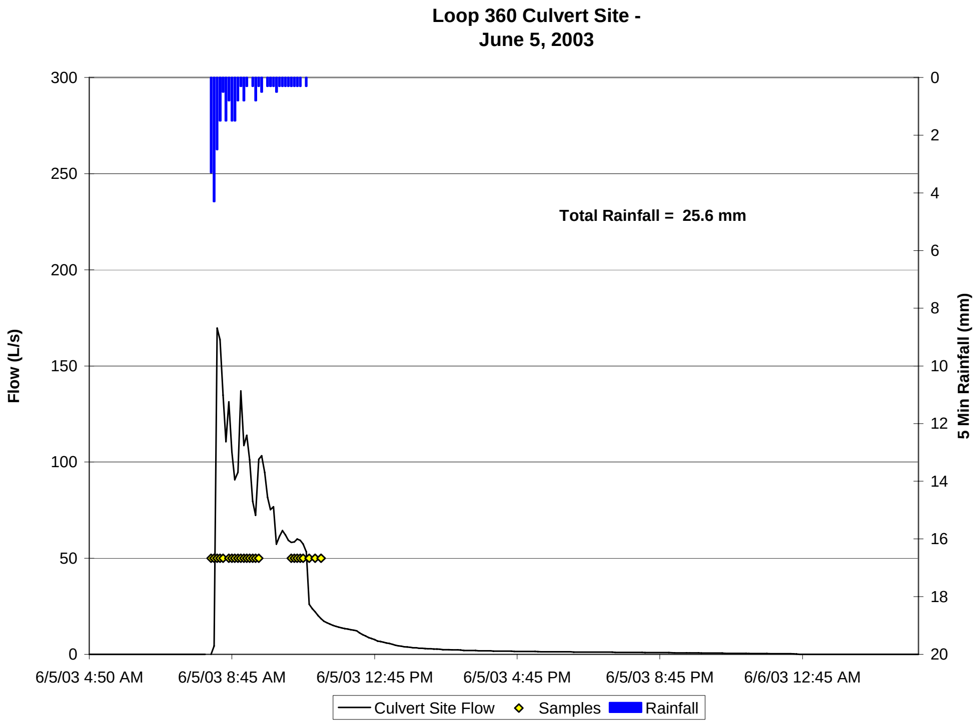

Figure I-17: Stormwater Runoff and Rainfall for Sample 2

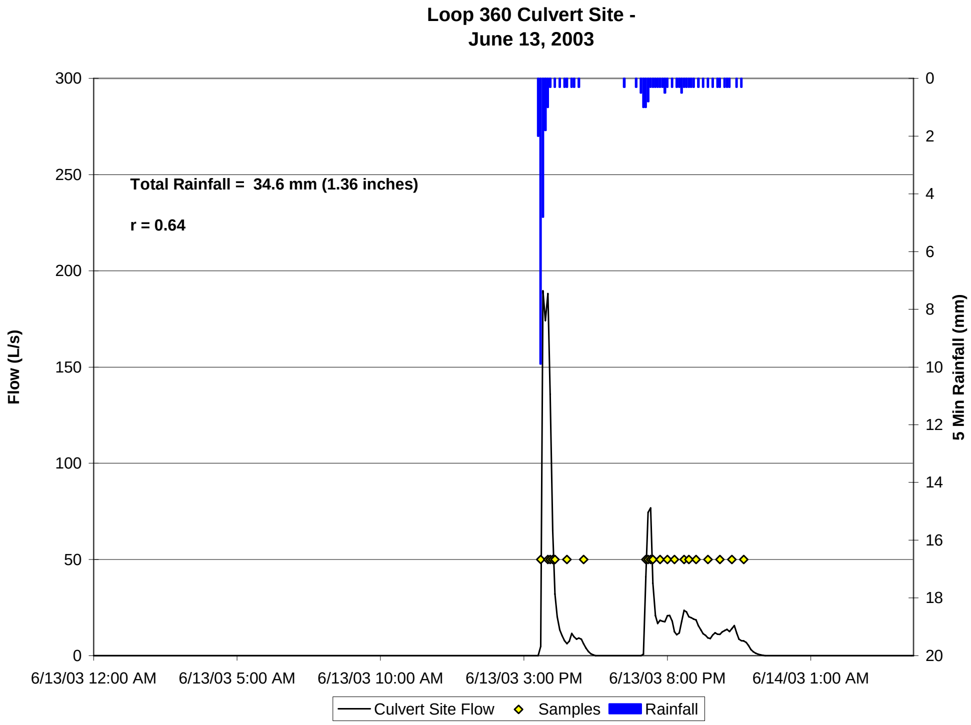

Figure I-18: Stormwater Runoff and Rainfall for Sample 3

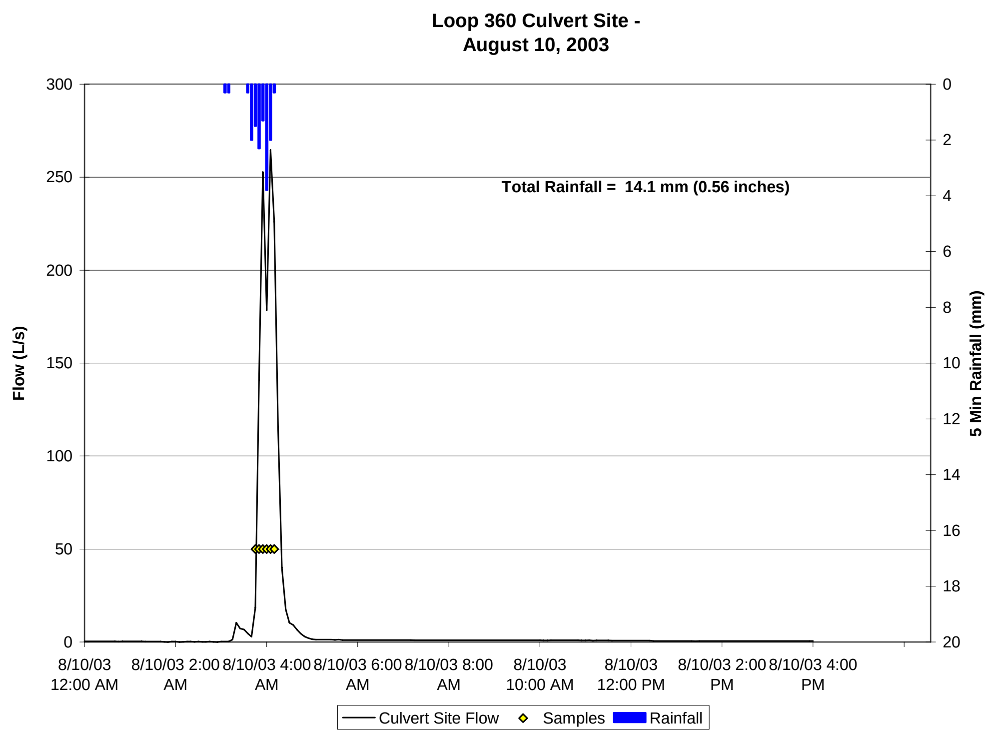

Figure I-19: Stormwater Runoff and Rainfall for Sample 4

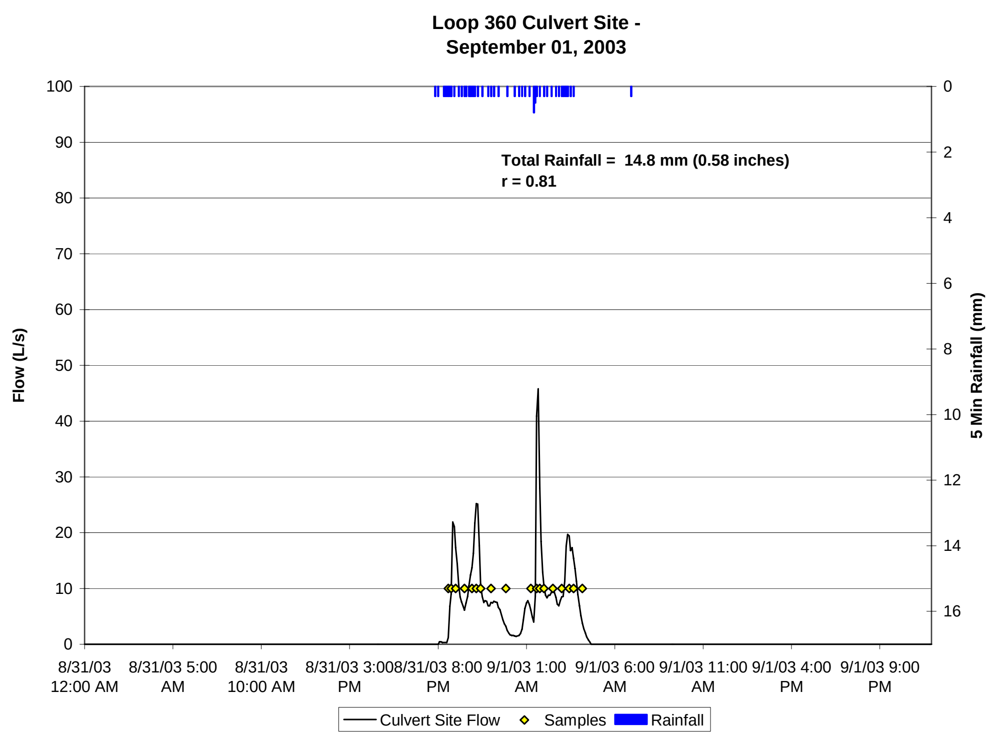

Figure I-20: Stormwater Runoff and Rainfall for Sample 5

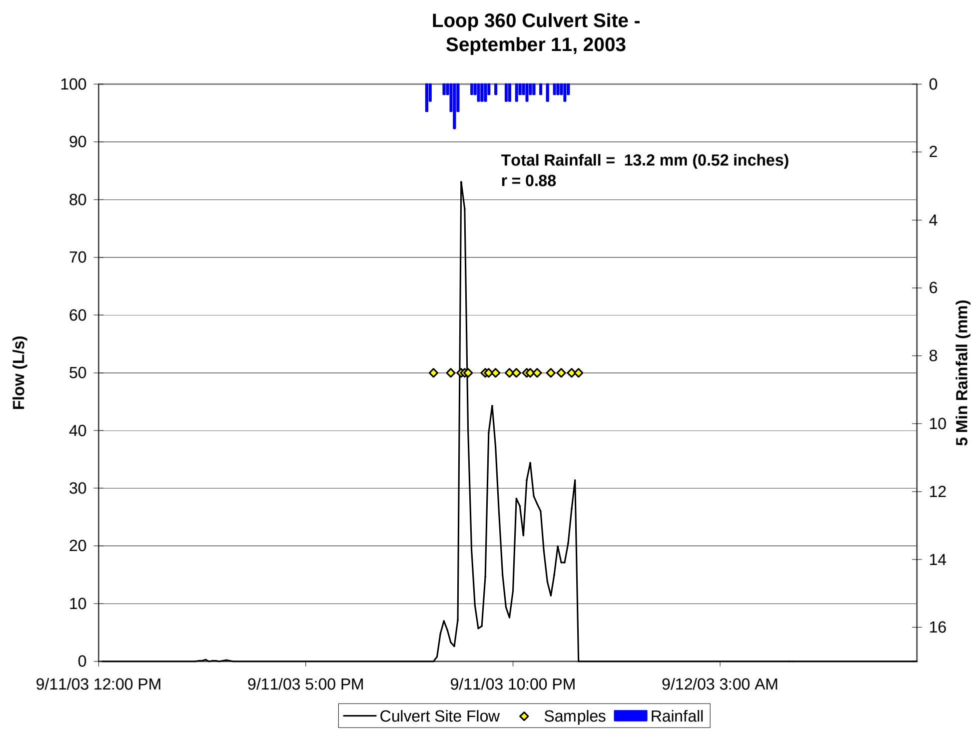

Figure I-21: Stormwater Runoff and Rainfall for Sample 6

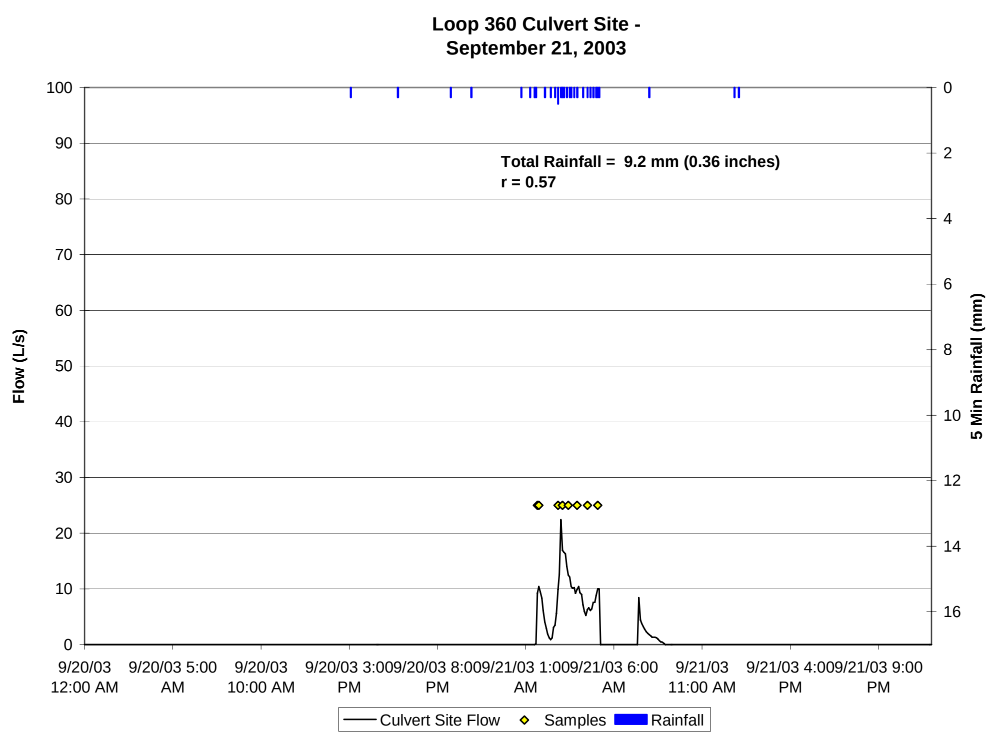

Figure I-22: Stormwater Runoff and Rainfall for Sample 7

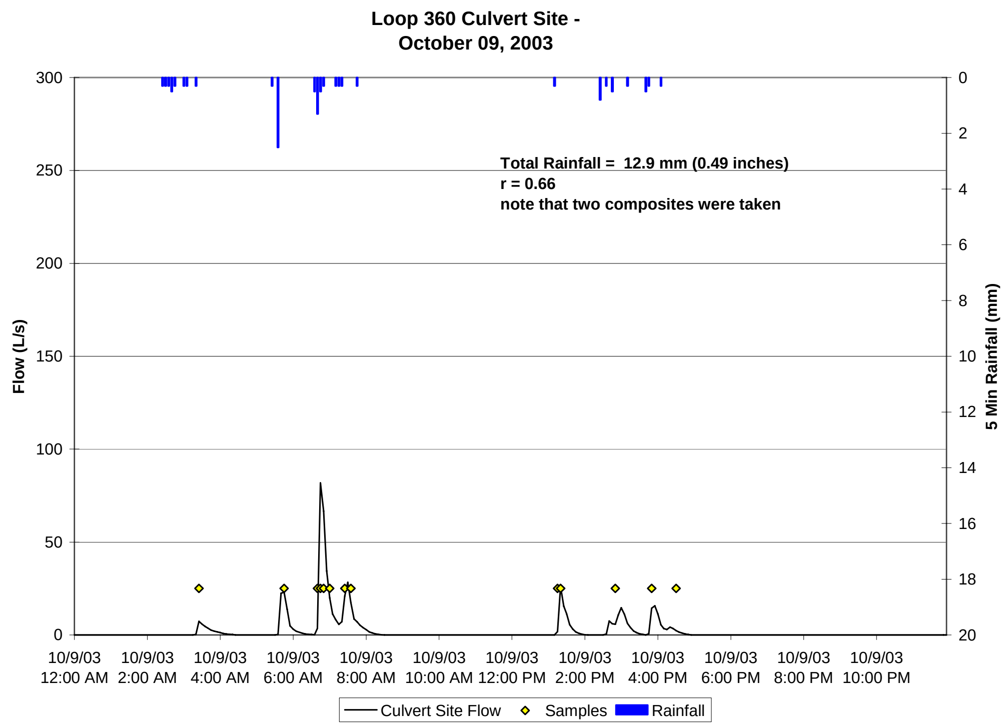

Figure I-23: Stormwater Runoff and Rainfall for Sample 8

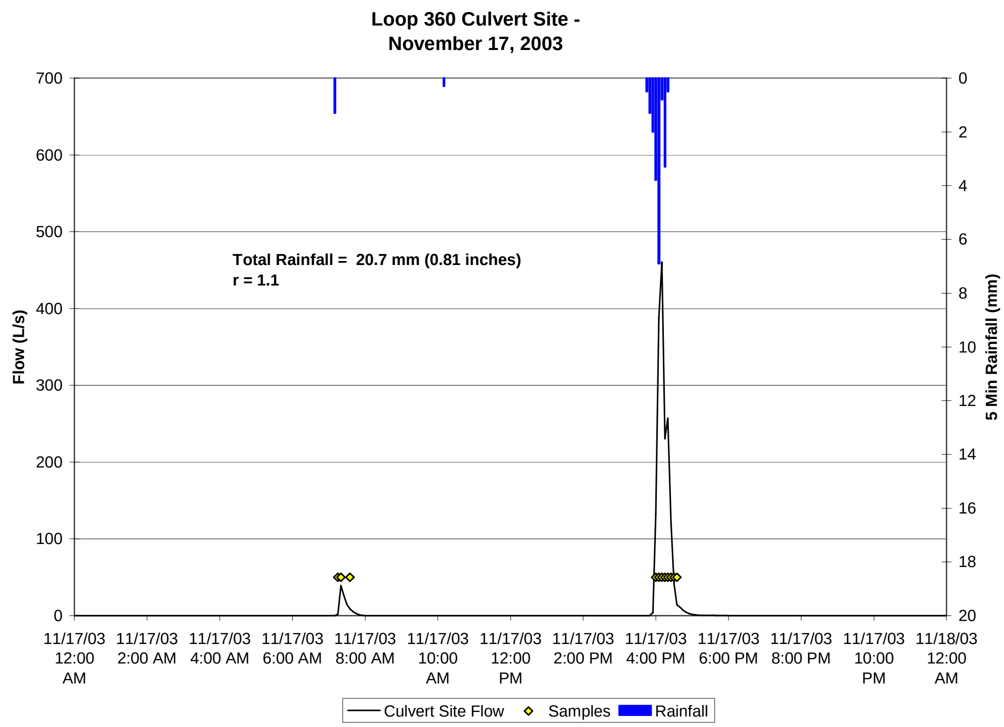

Figure I-24: Stormwater Runoff and Rainfall for Sample 9

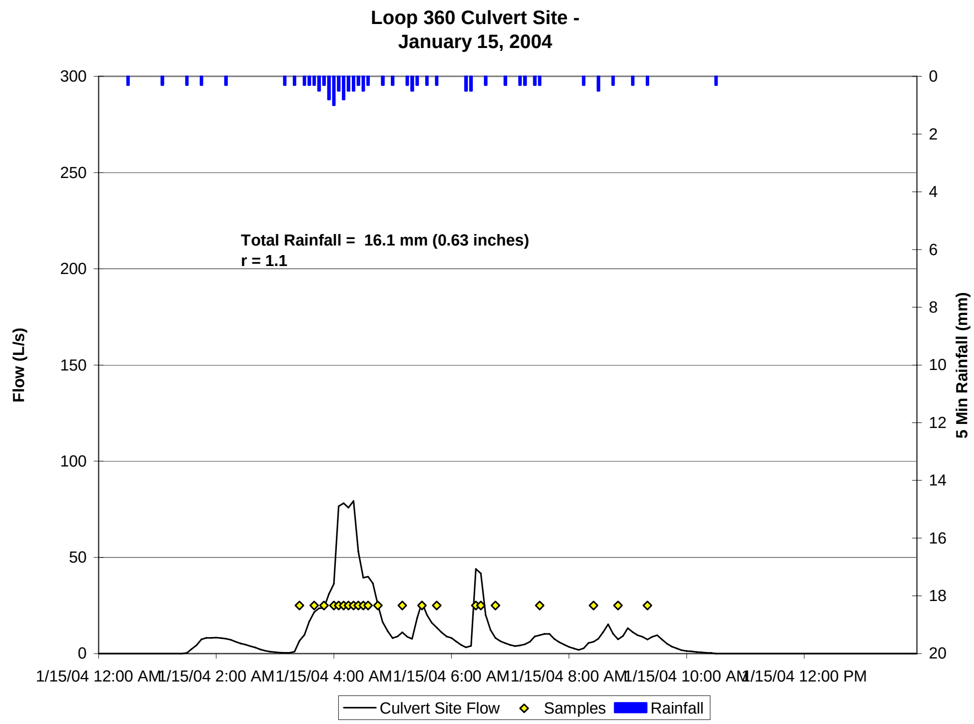

Figure I-25: Stormwater Runoff and Rainfall for Sample 10

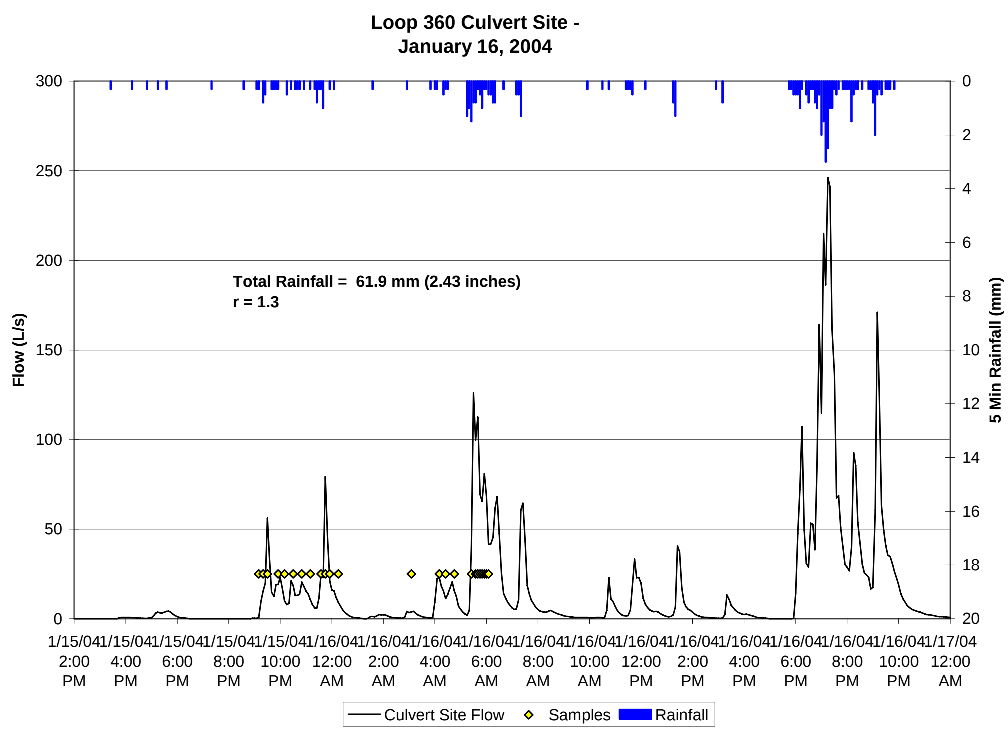

Figure I-26: Stormwater Runoff and Rainfall for Sample 11

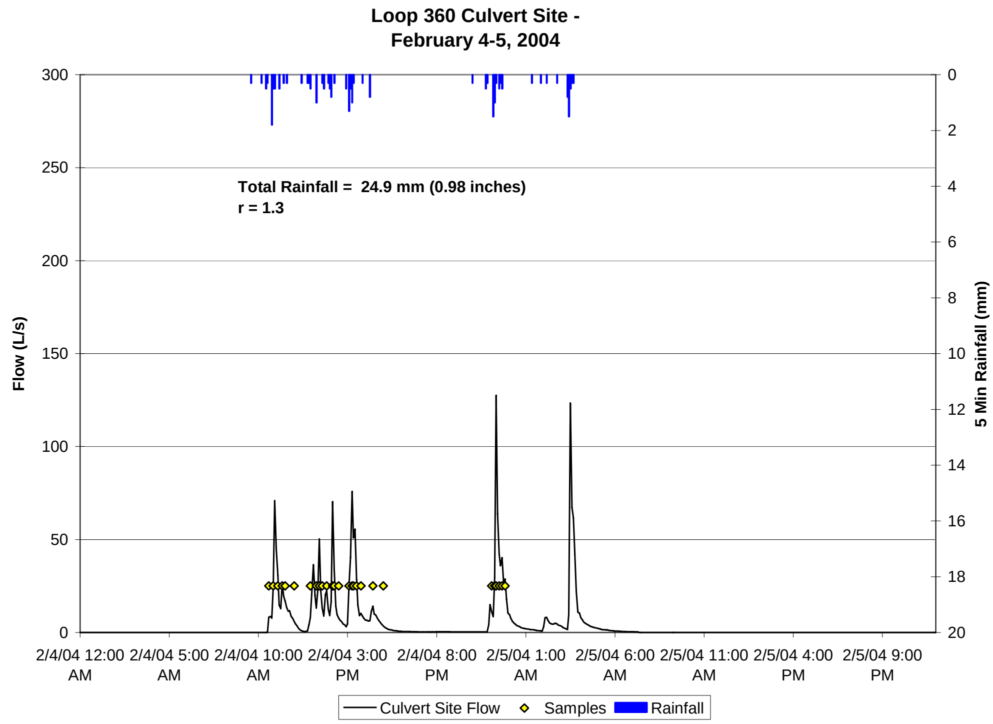

Figure I-27: Stormwater Runoff and Rainfall for Sample 12

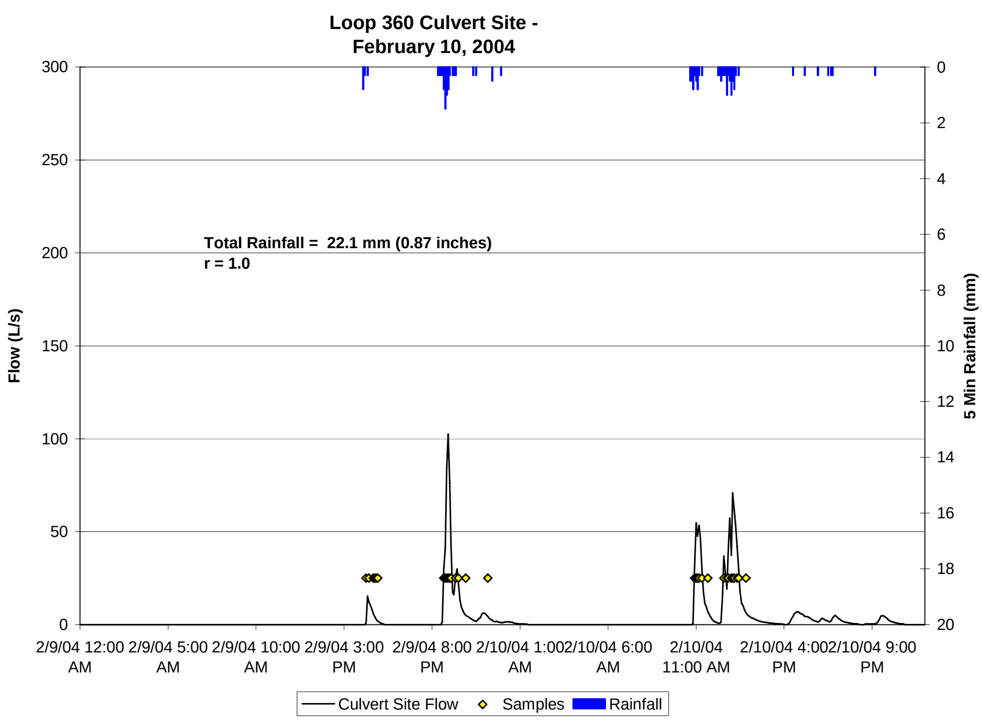

Figure I-28: Stormwater Runoff and Rainfall for Sample 13

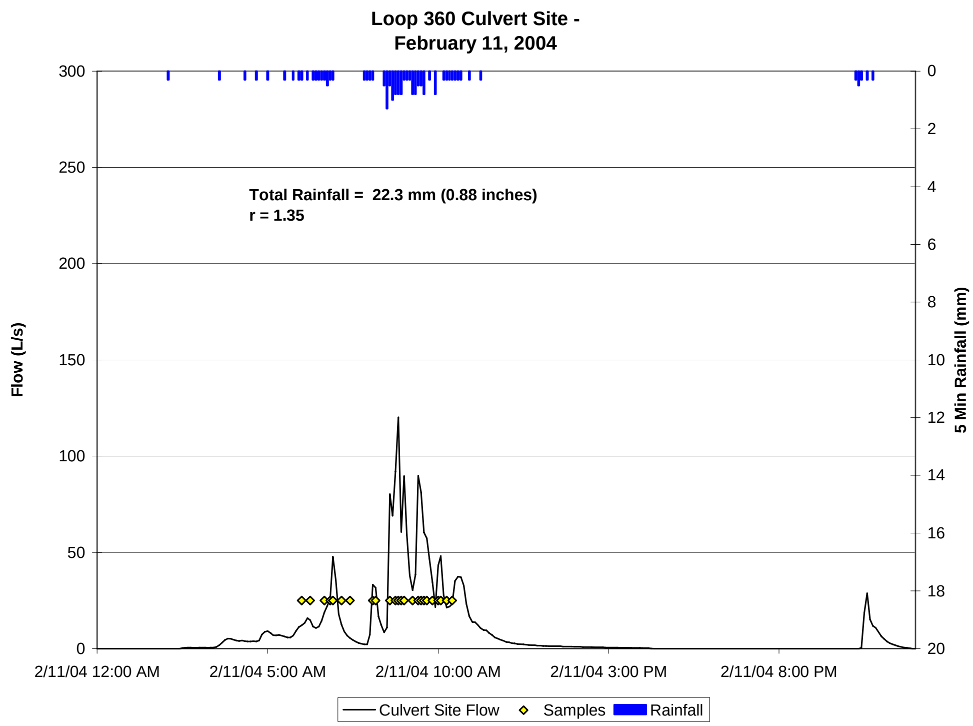

Figure I-29: Stormwater Runoff and Rainfall for Sample 14

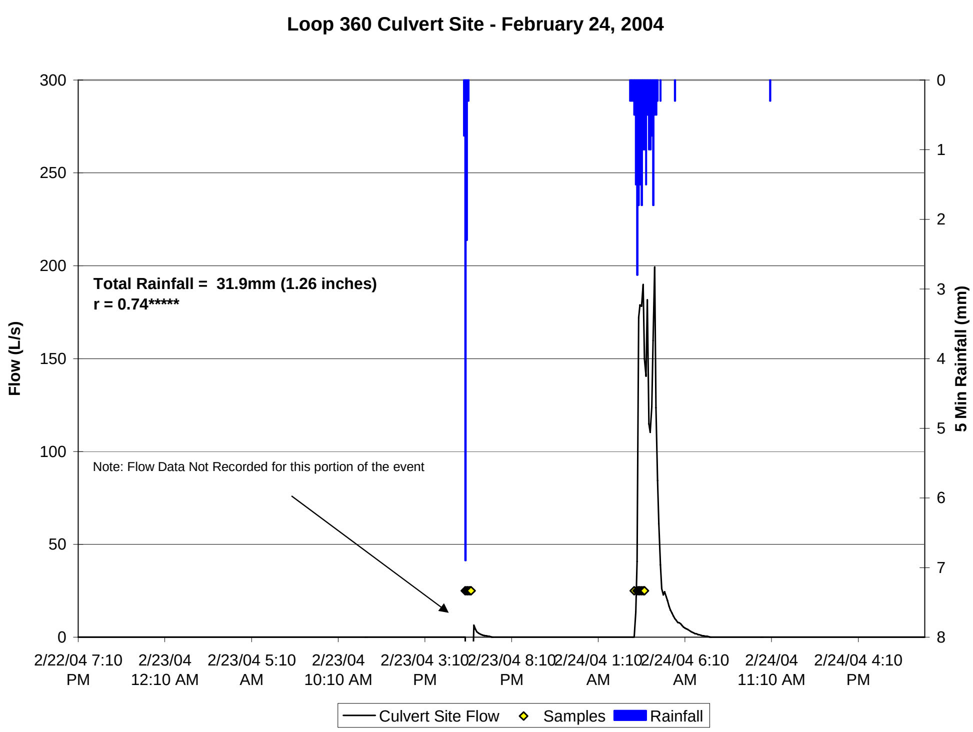

Figure I-30: Stormwater Runoff and Rainfall for Sample 15

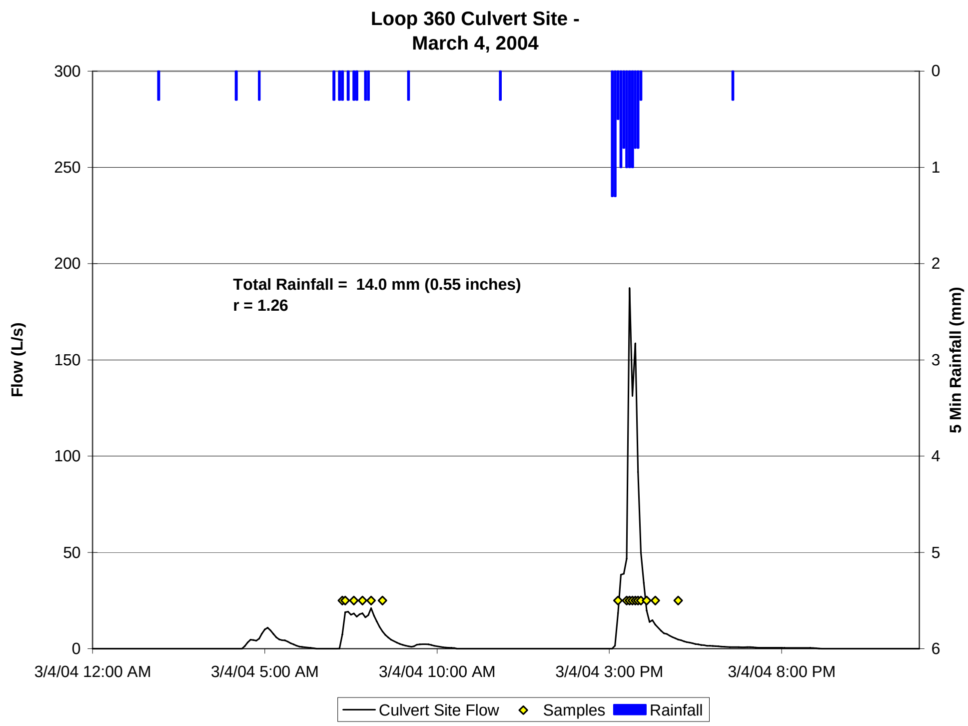

Figure I-31: Stormwater Runoff and Rainfall for Sample

APPENDIX II – MEASURED CONSTITUENT CONCENTRATIONS

Table II-1 Concentrations of Constituents in Flow-Weighted Samples of Runoff at the Bridge Site for All Rainfall Events Monitored, Austin, TX

	Date:	6/4/03	6/5/03	6/13/03	7/6/03	7/8/03	7/16/03	8/10/03	9/12/03	9/14/03
Constituent	**Units**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**
Copper, Total	µg/L	10.6	12.3	12.9	45.5	21.6	20.6	12.2	12.8	---
Copper, Dissolved	µg/L	4.8	3.24	2.74	7.08	6.34	5.66	3.05	4.77	---
Lead, Total	µg/L	5.95	8.56	9.57	28.3	14.9	13.4	9.35	6.32	---
Lead, Dissolved	µg/L	ND	ND	ND	ND	ND	ND	ND	ND	---
Zinc, Total	µg/L	125	132	168	406	203	246	171	108	---
Zinc, Dissolved	µg/L	31.4	15.5	22.3	16.5	25.5	13.3	24.8	16.2	---
Nitrogen, Nitrate (As N)	mg/L	0.520	0.220	0.210	0.350	0.260	0.280	0.760	0.290	---
Nitrogen, Kjeldahl, Total	mg/L	1.09	1.37	0.81	1.88	1.09	1.08	1.15	0.87	---
Chemical Oxygen Demand	mg/L	38.0	17.0	20.0	33.0	24.0	27.0	21.0	22.0	---
Phosphorus, Total (As P)	mg/L	0.140	0.170	0.070	0.280	0.150	0.150	0.040	ND	---
Phosphorus, Dissolved (As P)	mg/L	0.120	0.130	0.050	0.190	0.060	0.110	ND	ND	---
Suspended Solids - Total	mg/L	61.0	91.0	127	340	159	222	91.0	70.0	---
Suspended Solids - Volatile	mg/L	13*	16*	19*	49	32	26	17	19	---
Total Volatile Solids	mg/L	125	125	75	---	---	---	---	---	---
Fecal Coliform	cfu/100 mL	---	4000	---	---	---	---	---	---	7300
Oil & Grease, Total Recoverable	mg/L	---	4.71	---	---	---	---	---	---	4.81

	Date:	9/21/03	10/9/03	11/17/03	1/16/04	2/4/04	2/10/04	2/11/04	6/9/04
Constituent	**Units**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**
Copper, Total	µg/L	5.53	20.8	15.7	8.88	22.7	14.6	9.62	---
Copper, Dissolved	µg/L	3.34	5.99	4.23	2.71	3.46	3.6	2.62	---
Lead, Total	µg/L	1.75	9.57	8.39	4.4	13	8.9	6.66	---
Lead, Dissolved	µg/L	ND	ND	ND	ND	0.21	ND	ND	---
Zinc, Total	µg/L	69.2	200	173	73.3	223	123	77	---
Zinc, Dissolved	µg/L	38.3	30	28	41.1	38.7	51	39.9	---
Nitrogen, Nitrate (As N)	mg/L	0.420	0.410	0.185	0.118	0.577	0.375	0.199	---
Nitrogen, Kjeldahl, Total	mg/L	0.516	1.11	0.766	0.423	1.03	0.829	0.538	---
Chemical Oxygen Demand	mg/L	15.0	72.0	58.0	21.0	68.0	46.0	18.0	---
Phosphorus, Total (As P)	mg/L	0.080	0.120	0.090	0.050	0.130	0.070	0.030	---
Phosphorus, Dissolved (As P)	mg/L	0.040	0.060	ND	0.030	0.080	0.040	ND	---
Suspended Solids - Total	mg/L	11.0	104	108	31.0	158	67.0	37.0	---
Suspended Solids - Volatile	mg/L	8	28	20	20	26	19	7	---
Total Volatile Solids	mg/L	---	---	---	---	---	---	---	---
Fecal Coliform	cfu/100 mL	---	---	---	3900	---	---	---	7000
Oil & Grease, Total Recoverable	mg/L	---	---	---	3.2	---	---	---	6.44

* : Samples were analyzed past holding time
ND : Not Detected at the Reporting Limit

Table II-2 Concentrations of Constituents in Flow-Weighted Samples of Runoff at the Approach Highway Site for All Rainfall Events Monitored, Austin, TX

	Date:	6/4/03	6/5/03	6/13/03	8/10/03	9/1/03	9/11/03	9/14/03	9/21/03	10/9/03
Constituent	**Units**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**
Copper, Total	µg/L	9.07	22.5	15.3	32.8	21.2	24.5	---	13.7	47.5
Copper, Dissolved	µg/L	4.07	4.99	5.96	9.54	13.8	9.13	---	6.45	9.05
Lead, Total	µg/L	4.71	16.5	7.56	14.4	5.35	13.3	---	5.69	24.0
Lead, Dissolved	µg/L	ND	ND	ND	ND	ND	ND	---	ND	ND
Zinc, Total	µg/L	59.2	157	84	151	111	149	---	89.5	274
Zinc, Dissolved	µg/L	26.7	36.6	32.0	24.6	46.9	23.5	---	16.1	24.0
Nitrogen, Nitrate (As N)	mg/L	0.27	0.26	0.32	0.46	0.3	0.5	---	0.56	0.439
Nitrogen, Kjeldahl, Total	mg/L	0.58	1.27	0.94	7.08	1.58	1.95	---	1.02	2.03
Chemical Oxygen Demand	mg/L	27.0	11.0	27.0	57.0	60.0	41.0	---	33.0	137
Phosphorus, Total (As P)	mg/L	0.110	0.150	0.020	0.230	0.260	0.110	---	0.110	0.302
Phosphorus, Dissolved (As P)	mg/L	0.050	0.080	ND	0.080	0.200	0.040	---	0.050	0.156
Suspended Solids - Total (Residue, Non-Filterable)	mg/L	52.0	175	81.0	166	45.0	109	---	38.0	221
Suspended Solids - Volatile	mg/L	13*	23*	17*	36.0	10.0	31.0	---	17	49.4
Total Volatile Solids	mg/L	135	230	90	---	---	---	---	---	
Fecal Coliform	cfu/100 mL	---	10,000	---	---	---	---	4,000	---	
Oil & Grease, Total Recoverable	mg/L	---	9.5	---	---	---	---	3.59	---	

	Date:	11/17/03	1/15/04	1/16/04	2/5/04	2/10/04	2/11/04	2/24/04	3/4/04	6/9/04
Constituent	**Units**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**	**Conc'n**
Copper, Total	µg/L	35.6	15.1	15.7	29.1	30.4	20.4	17.7	24.8	---
Copper, Dissolved	µg/L	5.75	6.21	4.18	5.4	5.29	3.65	4.26	5.63	---
Lead, Total	µg/L	26	5.08	7.65	14.1	18.3	12.8	17.8	15.8	---
Lead, Dissolved	µg/L	ND	ND	ND	0.29	ND	ND	1.04	ND	---
Zinc, Total	µg/L	224	75.6	76.8	151	186	121	105	139	---
Zinc, Dissolved	µg/L	11.4	34.7	57.4	25.9	43.2	23.2	34.4	31.4	---
Nitrogen, Nitrate (As N)	mg/L	0.341	0.33	0.288	0.626	0.608	0.228	0.47	0.38	---
Nitrogen, Kjeldahl, Total	mg/L	1.31	0.633	0.757	1.33	1.47	0.813	0.489	1.44	---
Chemical Oxygen Demand	mg/L	84.0	39.0	38.0	73.0	93.0	44.0	64.0	71.0	---
Phosphorus, Total (As P)	mg/L	0.200	0.050	0.070	0.140	0.170	0.090	0.090	0.170	---
Phosphorus, Dissolved (As P)	mg/L	0.080	0.050	0.030	0.070	0.060	0.040	0.060	0.090	---
Suspended Solids - Total (Residue, Non-Filterable)	mg/L	177	29	68	136	150	90	176	194	---
Suspended Solids - Volatile	mg/L	27.0	9.00	31.0	30.0	28.0	20.0	25	34	---
Total Volatile Solids	mg/L	---	---							---
Fecal Coliform	cfu/100 mL	---	---	5,300						400
Oil & Grease, Total Recoverable	mg/L	---	---	5.64						ND

* : Samples were analyzed past holding time
ND : Not Detected at the Reporting Limit
++ : Two composite samples were collected on 10-09-03, the results presented here are weighted averages of the two samples based on the volume of flow measured for each sample.

APPENDIX III – USGS WATER QUALITY DATA
BARTON CREEK AT LOOP 360, AUSTIN, TX

Table III -1 Concentrations of Constituents in Barton Creek at Loop 360, Austin, TX

Constituent	**Units**	**Flow Type**	**Date Sampled** 6/9/00	11/2/00	12/4/00	4/16/01	5/6/01	5/30/01	8/26/01	11/15/01	2/13/02
Total Copper	µg/L	Storm	2.7	2			1.7		6.7	11.2	
		Base			ND	ND		ND			ND
Total Lead	µg/L	Storm	2	3			2		9	18	
		Base			ND	ND		ND			ND
Total Zinc	µg/L	Storm	20	18			36		38	47	
		Base			5	2		ND			2
Nitrate as N	mg/L	Storm	0.363	0.34			0.19		0.75	0.18	
		Base			0.4	0.09		0.04			0.17
Total Nitrogen	mg/L	Storm	1.22	0.85			0.73		2.9	4.4	
		Base			0.63	0.29					0.29
Chemical Oxygen Demand	mg/L	Storm	30	10			ND		60	110	
		Base			ND	ND		ND			ND
Total Phosphorus	mg/L	Storm	0.107	0.43			0.04		0.42	0.57	
		Base			ND	ND		ND			ND
Dissolved Phosphorus	mg/L	Storm	ND	0.05			ND		0.2	ND	
		Base			ND	ND		ND			ND
Total Suspended Solids	mg/L	Storm	104	41			145		280	1200	
		Base			ND	ND		ND			ND
Fecal Coliform	cfu per 100mL	Storm	11000	120000			92000		72000		
		Base			1	80		85		5	18

Constituent	**Units**	**Flow Type**	**Date Sampled** 4/10/02	6/30/02	10/19/02	12/9/02	12/31/02	1/22/03	2/20/03	4/29/03	1/16/04
Total Copper	µg/L	Storm		4.2					1.9		4.3
		Base	1		10.2	ND	ND	ND		ND	
Total Lead	µg/L	Storm		6					4		4.91
		Base	ND		ND	ND	ND	ND		ND	
Total Zinc	µg/L	Storm		20					10		25
		Base	ND		4	11	4	2		ND	
Nitrate as N	mg/L	Storm		0.31					0.28		0.35
		Base	0.07		0.12	0.23	0.17	0.16		0.04	
Total Nitrogen	mg/L	Storm		2.1						1.3	1.1
		Base	0.23		0.31	0.46	0.29	0.3			
Chemical Oxygen Demand	mg/L	Storm		40					30		20
		Base	ND		ND	ND	ND	ND		ND	
Total Phosphorus	mg/L	Storm		0.22					0.12		0.14
		Base	ND		0.03	0.02	ND	ND		ND	
Dissolved Phosphorus	mg/L	Storm		ND					0.1		0.04
		Base	ND		ND	ND	ND	ND		ND	
Total Suspended Solids	mg/L	Storm		396					226		56
		Base	ND		ND	12	ND	ND		ND	
Fecal Coliform	cfu per 100mL	Storm	10600						2700		
		Base			800	168	5			52	

ND : Not detected at reporting limits